Universidade de Aveiro Departamento de Biologia
Ano 2014

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INTERACTIONS OF CETACEANS WITH SPANISH AND PORTUGUESE FISHERIES IN ATLANTIC WATERS: COSTS, BENEFITS AND IMPLICATIONS FOR MANAGEMENT

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Biologia, realizada sob a orientação científica do **Doutor José Vítor de Sousa Vingada**, Professor Auxiliar do Departamento de Biologia da Universidade do Minho; do **Doutor Graham John Pierce**, Professor do Oceanlab, Universidade de Aberdeen e Professor Convidado do Departamento de Biologia da Universidade de Aveiro; da **Doutora Begoña Santos Vázquez** e do **Doutor Julio Martínez Portela**, Investigadores do Instituto Español de Oceanografía.

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Wer an der Küste bleibt,
kann keine neuen Ozean*e entdecken*

Fernão de Magalhães (Ferdinand Magellan)

o júri

presidente

Prof. Doutor António Sousa Pereira
Full professor, Departamento de Electrónica, Telecomunicações e Informática (DETI)

Prof. Doutor Amadeu Soares
Full professor and head of department, Departamento de Biologia, Universidade de Aveiro, Portugal

Doutor Santiago Cerviño
Researcher at Instituto Espanol de Oceanografia (IEO), Centro Oceanografico de Vigo, Spain

Doutor Renaud de Stephanis
Researcher at Estación Biológica de Doñana, CSIC, Spain

Doutora Mar Sacau
Researcher at Instituto Espanol de Oceanografia (IEO), Centro Oceanografico de Vigo, Spain

Prof. Doutor Graham Pierce
Visiting chair CESAM and Departamento de Biologia, Universidade de Aveiro, Portugal
professor Oceanlab, University of Aberdeen, UK

agradecimentos

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palavras-chave

interações entre pescas e cetáceos, depredação, capturas acidentais, inquérito por entrevista, observação a bordo, medidas de mitigação, participação de "partes interessadas"

resumo

Com a finalidade de melhorar a compreensão das interações entre cetáceos e atividades pesqueiras em águas Atlânticas, esta tese analisa as interações entre cetáceos e artes de pesca Portuguesas e Espanholas a operar em águas Ibéricas e do sudoeste Atlântico.
Diferentes metodologias oportunistas de investigação foram aplicadas, incluindo entrevistas com pescadores (principalmente capitães de embarcação) e observações a bordo, quer por observadores de pesca ou capitães, com o fim de 1) descrever os diferentes tipos de interações; 2) identificar potenciais *hotspots* de interações cetáceos-pesca e quais as espécies de cetáceos mais envolvidas; e quantificar a dimensão e consequências destas interações em termos de custos e benefícios, tanto para cetáceos como para as atividades pesqueiras. Mais ainda, a adequabilidade de diferentes estratégias de mitigação destas interações foi avaliada e discutida.

Os resultados obtidos neste trabalho indicam que diferentes espécies de cetáceos interagem frequentemente com embarcações de pesca Portuguesas e Espanholas, muitas vezes com consequências positivas (por ex. com os cetáceos frequentemente indicando cardumes durante a pesca de cerco), mas maioritariamente com consequências negativas (predação pelos cetáceos, levando à perda de pescado, danificação dos aparelhos de pesca e capturas acidentais de cetáceos). No entanto, perdas económicas significativas e altas taxas de captura acidental são raramente declaradas, acontecendo apenas com alguns tipos de pesca e com certas espécies de cetáceos. Na Galiza, perdas económicas substanciais podem resultar de danos nas redes fixas artesanais pelo roaz-corvineiro (*Tursiops truncatus*), bem como importantes reduções das capturas por golfinho-comum (*Delphinus delphis*) devido à dispersão de cardumes na pesca de cerco. Altas taxas de mortalidade de cetáceos por captura acidental são declaradas na pesca de arrasto, principalmente de golfinho-comum e quando o arrasto é realizado a profundidades menores que 350 m, assim como em pescas de rede de emalhar e tresmalho em zonas costeiras (principalmente de golfinho comum e roaz-corvineiro). Em águas do Sudoeste Atlântico, cachalotes podem reduzir significativamente taxas de captura por predação em pesca comercial de palangre de fundo.

A grande diversidade de interações cetáceos-pesca observadas na área de estudo indicam que estratégias de gestão especificas são necessárias para reduzir impactos negativos tanto nas pescas como nos cetáceos.

Dispositivos de alerta (*pingers*) poderiam ser usados para prevenir pequenos cetáceos de se aproximarem e ficarem presos nas redes fixas e redes de cerco, sempre que possam ser possam ser excluídas situações de habituação dos cetáceos ao som dos *pingers*, assim como efeitos negativos em espécies de cetáceos não alvo (como exclusão de habitat) e espécies-alvo de pesca (redução de capturas). Para sardinha e carapau, duas espécies-alvo muito importantes na pesca Ibérica Atlântica, nenhuma reação negativa ao som do *pinger* foi detectada durante experiências em tanques conduzidas no âmbito desta tese. Capturas acidentais durante pesca de arrasto poderiam ser reduzidas com a implementação de restrições de tempo/área na atividade de pesca. Adicionalmente, a redução de interações pode ser conseguida se as embarcações evitarem áreas de pesca com grande abundância de cetáceos, integrando medidas de minimização de pistas sonoras que possam atrair cetáceos às embarcações. A depredação de cetáceos sobre capturas de palangre de fundo poderia ser reduzida recorrendo ao encapsulamento dos anzóis ("sistema guarda-chuva"), uma vez que as taxas de captura de peixe não são afectadas por esta modificação.

A pesca com armadilha, como alternativa à pesca de redes de fundo fixas e de palangre de fundo tem também o potencial de reduzir a depredação e capturas acidentais de cetáceos, se taxas de captura semelhantes forem conseguidas. Incentivos económicos, como a eco-certificação de métodos de pesca não prejudiciais às populações de cetáceos, devem ser promovidos de modo que possam constituir uma fonte adicional de rendimento para pescadores afectados negativamente por estas interações, o que por sua vez poderá também aumentar a disponibilidade dos pescadores em aceitar e adoptar medidas mitigadoras. Apesar dos métodos oportunistas aplicados neste trabalho poderem ter certas restrições no que respeita à precisão e fiabilidade dos dados, os resultados são consistentes com estudos anteriores realizados na mesma área. Mais ainda, eles permitem a participação ativa dos pescadores, que podem aportar conhecimento técnico e ecológico importante necessário para a gestão e conservação de cetáceos.

keywords cetacean-fishery interactions, depredation, bycatch, interview survey, on-board observations, mitigation measure, stakeholder participation

abstract

With the aim to provide new insights into operational cetacean-fishery interactions in Atlantic waters, this thesis assesses interactions of cetaceans with Spanish and Portuguese fishing vessels operating in Iberian and South West Atlantic waters. Different opportunistic research methodologies were applied, including an interview survey with fishers (mainly skippers) and on-board observations by fisheries observers and skippers, to describe different types of interactions and to identify potential hotspots for cetacean-fishery interactions and the cetacean species most involved, and to quantify the extent and the consequences of these interactions in terms of benefits and costs for cetaceans and fisheries. In addition, the suitability of different mitigation strategies was evaluated and discussed.

The results of this work indicate that cetaceans interact frequently with Spanish and Portuguese fishing vessels, sometimes in a beneficial way (e.g. cetaceans indicate fish schools in purse seine fisheries), but mostly with negative consequences (depredation on catch, gear damage and cetacean bycatch). Significant economic loss and high bycatch rates are, however, only reported for certain fisheries and associated with particular cetacean species. In Galician fisheries, substantial economic loss was reported as a result of bottlenose dolphins damaging artisanal coastal gillnets, while high catch loss may arise from common dolphins scattering fish in purse seine fisheries. High cetacean bycatch mortality arises in trawl fisheries, mainly of common dolphin and particularly during trawling in water depths below 350 m, and in coastal set gillnet fisheries (mainly common and bottlenose dolphins). In large-scale bottom-set longline fisheries in South West Atlantic waters, sperm whales may significantly reduce catch rates through depredation on catch.

The high diversity of cetacean-fishery interactions observed in the study area indicates that case-specific management strategies are needed to reduce negative impacts on fisheries and cetaceans. Acoustic deterrent devices (pingers) may be used to prevent small cetaceans from approaching and getting entangled in purse seines and set gillnets, although possible problems include cetacean habituation to the pinger sounds, as well as negative side effects on non-target cetaceans (habitat exclusion) and fisheries target species (reduced catch rates). For sardine and horse mackerel, target species of Iberian Atlantic fisheries, no aversive reaction to pinger sounds was detected during tank experiments conducted in the scope of this thesis.

Bycatch in trawls may be reduced by the implementation of time/area restrictions of fishing activity. In addition, the avoidance of fishing areas with high cetacean abundance combined with the minimization of fishery-specific sound cues that possibly attract cetaceans, may also help to decrease interactions. In large-scale bottom-set longline fisheries, cetacean depredation on catch may be reduced by covering hooked fish with net sleeves ("umbrellas") provided that catch rates are not negatively affected by this gear modification.

Trap fishing, as an alternative fishing method to bottom-set gillnetting and longlining, also has the potential to reduce cetacean bycatch and depredation, given that fish catch rates are similar to the rates obtained by bottom-set gillnets and longlines, whereas cetacean by-catch is unlikely. Economic incentives, such as the eco-certification of dolphin-safe fishing methods, should be promoted in order to create an additional source of income for fishers negatively affected by interactions with cetaceans, which, in turn, may also increase fishers' willingness to accept and adopt mitigation measures. Although the opportunistic sampling methods applied in this work have certain restrictions concerning their reliability and precision, the results are consistent with previous studies in the same area. Moreover, they allow for the active participation of fishers that can provide important complementary ecological and technical knowledge required for cetacean management and conservation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ACAP: Agreement on the Conservation of Albatrosses and Petrels

ACCOBAMS: Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area

ADD: Acoustic Deterrent Device

AHD: Acoustic Harassment Device

AIC: Akaike Information Criterion

ASCOBANS: Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas

BMC: Brazil–Malvinas Confluence

CCAMLR: Commission for the Conservation of Antarctic Marine Living Resources

CITES: Convention on International Trade in Endangered Species of Wild Fauna and Flora

CMS: Convention on the Conservation of Migratory Species of Wild Animals

CODA: Cetacean Offshore Distribution and Abundance

CPUE: Catch Per Unit Effort

EC: European Commission

EEC: European Economic Community

EEZ: Exclusive Economic Zone

EIA: Enzyme Immunoassay

FICZ: Falkland Island Inner Conservation Zone

FOCZ: Falkland Island Outer Conservation Zone

FAO: Food and Agriculture Organization of the United Nations

FEK: Fishers' Ecological Knowledge

FV: Fishing vessel

GAM: Generalized Additive Model

GAMM: Generalized Additive Mixed Model

GIS: Geographic Information System

GLM: Generalized Linear Model

GLS: Generalized Least Square

IATTC: Inter-American Tropical Tuna Commission

ICCAT: International Commission for the Conservation of Atlantic Tuna

INCF: Instituto de Conservaçao da Natureza e das Florestas

ICES: International Council for the Exploration of the Sea

ISSCFG: International Standard Statistical Classification of Fishing Gear

IUCN: International Union for Conservation of Nature

IWC: International Whaling Commission

JNCC: Joint Nature Conservation Committee

LEK: Local Ecological Knowledge

LME: Linear Mixed Effects

MED: Mammal Excluder Device

MSC: Marine Stewardship Council

PDMD: Physical Depredation Mitigation Device

SAC: Special Areas of Conservation

SCANS: Small Cetaceans in the European Atlantic and North Sea

SCI: Site of Community Importance

SST: Sea Surface Temperature

STECF: Technical and Economic Committee for Fisheries

WGEAWESS: Working Group on Ecosystem Assessment of Western Shelf Seas

WGMME: Working Group on Marine Mammal Ecology

THESIS OUTLINE

This thesis is presented as a series of chapters. Excluding the general introduction and discussion, all chapters are adapted from papers that have been published, submitted to a journal or are in preparation. Authorship of chapters for publication is shared with other researchers who have made significant contributions to the work. All co-authors, the current publication status of each paper, and the contribution of the author of this PhD thesis to each paper, are listed at the beginning of the chapters concerned.

Chapter 1 provides a general introduction to cetacean-fishery interactions, the characteristics of the study area and local fisheries, the description of cetacean species occurring in the study area, their conservation status and available information on their interactions with fisheries. The introduction also gives a short overview on strategies to mitigate and monitor cetacean-fishery interactions, and their implementation in local fisheries policy.

Chapter 2 presents baseline information for the analysis of cetacean-fishery interactions in Iberian Atlantic waters. Based on several new datasets, it describes the species composition of cetaceans in the study area and their habitat preferences, i.e. their occurrence patterns as related to the coastal morphology, oceanographic conditions (e.g. water depth) and marine living resources. In addition, the potential for cetacean-fishery interactions is discussed by assessing the overlap between preferred cetacean habitats and the main fishing grounds of Galician and Portuguese fisheries. As cetacean sighting data are derived from different opportunistic sampling methods, including an interview survey with local fishers (mainly skippers) and vessel-based observations by skippers and fisheries observers, the reliability and performance of each survey method is also evaluated.

Chapter 3 assesses operational cetacean-fishery interactions in Galicia, the most important fishing region in Spain. The results presented in this chapter derive from a face-to-face interview survey with local fishers and include information on the types of interactions observed by Galician fishers and the scale of interaction, i.e. the frequency of occurrence, economic loss and bycatch rates associated with interactions. In addition, specific problematic interactions (fishing gears, cetacean species and fishing areas mainly affected) are identified. Different case-specific strategies to reduce interactions are described and discussed at the end of this chapter.

Chapter 4 examines possible side effects of acoustic deterrent devices ("pingers"), designed to mitigate cetacean-fishery interactions, on two commercially important target species of Spanish and Portuguese fisheries: European sardine and Atlantic horse mackerel. With the aim to assess whether the use of pingers may have a negative effect on catch rates in fisheries directed at these species, fish were exposed to different commercially available pinger models in tank experiments in the laboratory, analysing their behavioural (changes in swimming behaviour) and physiological (differences in blood cortisol concentration) stress response to the pinger sounds. The significance and implications of the experimental results, as well as the feasibility of pinger use in local fisheries are discussed.

Chapter 5 describes cetacean-fishery interactions in distant Atlantic waters. Interactions of sperm whales and seabirds with Spanish large-scale bottom-set longline fisheries were investigated by means of on-board observations in the High Seas of the South West Atlantic, assessing the extent of sperm whale depredation on catch and cetacean (and sea bird) bycatch. The relationship between sperm whale sightings, occurrence of depredation, catch rates, and environmental- and fishery-related variables are also analysed. Moreover, conclusions about the efficiency and feasibility of a modified longline design (including so-called “umbrellas”) for the mitigation of interactions are provided.

Chapter 6 provides a general discussion of this work, including a short synthesis of the main results and conclusions, their wider implications for the management and future research of cetacean-fishery interactions, as well as a brief discussion about the suitability of different research methodologies to study cetacean-fishery interactions.

Appendix E includes an additional research article about cetacean-fishery interactions, written during the PhD study period. The study analyses interactions of cetaceans, in particular killer and false killer whale, with Spanish surface longline fisheries in distant Atlantic waters as recorded by on-board observers and skippers. The results presented include information on depredation and bycatch rates, as well as an assessment of the relationships between catch rates, cetacean presence, the occurrence of depredation and environmental variables.

Conference presentations

Oral presentations

Sabine Goetz, Read, F.L., Santos, M.B. and G.J. Pierce. Conflicts between fisheries and cetaceans in Galicia: results of an interview survey with local fishermen. Bycatch of cetaceans. Present scenarios and mitigation measures. SAFESEA conference, Figueira da Foz, Portugal. April 2011.

Sabine Goetz, Laporta, M., Portela, J. and G.J. Pierce. Interactions of sperm whales (*Physeter macrocephalus*) and bottom-set longlines for toothfish in the High Seas of the South West Atlantic. Marine EcoSystems & Sustainability Conference (MESS), Aberdeen, UK, December 2009.

Sabine Goetz, Portela, J.M., Laporta, M., del Río, J.L., Sacau, M., Vilela, R., Pierce, G.J., M.B. Santos and T. Patrocinio. Preliminary results of Exploratory Fishing targeting *Dissostichus eleginoides* and *Macrourus sp*. on the High Seas of the South West Atlantic. ICES Annual Science Conference, Berlin, Germany. September 2009.

Sabine Goetz, Hernandez Milian, G., Varela Dopico, C., Rodriguez Gutierrez, J., Romón, J., Fuertes Gamundi, J.R., Ulloa, E., Tregenza, N.J.C., Smerdon, A., Otero, M.G., Tato, V., Wang, J., Santos, M.B., López, A., Lago, R., Portela, J. and G.J. Pierce. Results of a short study of interactions of cetaceans and longline fisheries in Atlantic waters: environmental correlates of catch and depredation events. NAFO Symposium – The Role of marine mammals in the Ecosystem in the 21st century, Dartmouth, Canada. September/October 2008.

Posters

Sabine Goetz, Read, F.L., Santos, M.B. and G.J. Pierce. Conflicts between fisheries and cetaceans in Galicia, NW Spain: Preliminary results of an interview survey with local fishermen. 24th Annual Conference of the European Cetacean Society. Stralsund, Germany. March 2010.

Sabine Goetz, Laporta, M., Portela, J. and G.J. Pierce. Depredation of sperm whales (*Physeter macrocephalus*) on bottom-set longlines for toothfish (*Dissostichus eleginoides*) on the High Seas of the South West Atlantic. 23rd Annual conference of the European Cetacean Society, Istanbul, Turkey. March 2009.

CHAPTER 1

General Introduction

1.1 CETACEAN-FISHERY INTERACTIONS

The phenomenon of cetacean-fishery interactions has become of great concern among scientists, not only because of the increasing number of reported cases during the last decades, but also because of the difficulties in quantifying their impact on cetacean populations and fisheries economy (Harwood, 1983). Due to the rapid expansion of fisheries and the continuous progress in fishing technology since the 1960s, conflicts between cetaceans and fisheries have become more and more frequent (Crespo and Hall, 2001). In addition, increased public awareness of wildlife conservation has drawn increased attention to the problem (Beverton, 1985). Deriving effective management measures is complex since the interests of the fishing industry on the one hand, and the principles of current conservation policy on the other, need to be brought into accordance (Proelss *et al*., 2011).

Interactions are reported for many cetacean species and affect a large variety of small-scale/artisanal and large-scale/industrial fisheries all around the world (see Northridge, 1984; Read, 1996; Reeves *et al*., 2001; Bearzi, 2002; Zollet and Rosenberg, 2005; Young and Iudicello, 2007; Hamer *et al*., 2012 and Reeves e*t al*., 2013 for reviews). A general distinction can be made between "operational interactions", where cetaceans interact directly with the fishing gear and "biological interactions", including the ecological competition between cetaceans and fisheries for shared resources and the transmission of parasites from marine mammals (particularly pinnipeds) to commercial fish species (IUCN, 1981).

Operational interactions can be positive or negative. The best-known example of positive cetacean-fishery interactions is probably the Eastern Tropical Pacific tuna fishery, where the fishers benefit from the strong ecological association between dolphins and tuna (Allen, 1985). In this fishery, the presence of dolphin schools is used as a cue to detect tuna concentrations and dolphins may also assist in the fishing process by herding the fish towards the fishing gear, increasing catch rates (e.g. Hall and Donovan, 2002; Reeves and Reijnders, 2002). The majority of operational interactions, however, have negative consequences, either for cetaceans or fisheries. Cetaceans are frequently observed to forage around fishing gear, taking bait or captured fish from nets or hooks, a behaviour referred to as "depredation" (Reeves *et al*., 2001). Depredation particularly occurs on fixed fishing gear with long soak times (e.g. bottom-set gillnets, trammel nets and longlines), where food is concentrated and easily accessible to the animals (Harwood, 1983). Apart from catch reduction (Lauriano *et al*., 2004; Gilman *et al*., 2006a; Gazo *et al*., 2008; Rocklin *et al*., 2009; Silva *et al*., 2011), depredation may also lead to damaged fishing equipment as the animals may tear holes into the nets, break fishing lines or twist the gear while they attempt to remove prey or accidently get entangled in the gear (Kock *et al*., 2006; Zollet and Read, 2006; Brotons *et al*., 2008a; Bearzi *et al*., 2011). Catch loss can also occur when small cetaceans interfere during the fishing operation, for instance in purse seines fisheries, where the presence of the cetaceans may cause fish schools to sink or scatter before the net is pursed (Wise *et al*., 2007). Although the overall economic impact of catch loss and gear damage through cetacean-fishery interactions is mostly quantified as modest, monetary loss can be substantial for some fisheries, especially in areas with acute conflict (Northridge, 1984; Gilman *et al*., 2006a; Brotons *et al*., 2008a; Lauriano *et al*., 2009).

Apart from the negative impacts on fisheries, operational interactions can also have adverse effects on cetaceans, including cetacean injury or mortality from bycatch, i.e. the unintentional catch/accidental entanglement in fishing gear, and from retaliatory measures taken by fishers, as well as changes in distribution and habitat use. If the cetaceans move to areas with high fishing effort for fishery-associated feeding, this could further increase bycatch mortality (Reeves *et al*., 2001); if they move to areas with lower fish abundance this may adversely affect their energy budgets (e.g. reduced food intake, increased foraging and feeding time, etc).

Cetacean bycatch is primarily a problem in fisheries operating bottom-set gillnets and pelagic trawls (Read, 1996; Zollet and Rosenberg, 2005; Young and Iudicello, 2007; Reeves *et al*., 2013). Accidental entanglement in the gear may occur during opportunistic feeding on catch, but also, as in the case of gillnets, when cetaceans fail to detect fishing nets while travelling (Tregenza, 1999). Bycatch is considered a serious threat to cetacean populations worldwide, particularly if threatened species are affected (IWC, 1994; Kaschner, 2003; Young and Iudicello, 2007).

Biological interactions are more complex and more difficult to assess than operational interactions (Northridge and Hofman, 1999). Fisheries may affect cetaceans by decreasing the abundance of their prey, whereas cetaceans may potentially reduce the amount of fish available to fisheries (Reeves *et al*., 2001). However, since fisheries and cetaceans rarely exploit the same size classes of fish in the same area, it is very difficult to predict how the resource reduction by one group exactly affects the resource availability for the other group (Harwood, 1983). Operational interactions are typically local and immediate in their manifestation, and therefore easier to assess. Nevertheless, quantifying the negative impact caused to fisheries by cetaceans and vice versa can also be challenging. Catch loss can be calculated by counting damaged fish and estimating their potential value. Fish that are removed entirely or scared away from the gear, however, cannot easily be quantified accurately. Assessing the economic loss through gear damage is also a very complex task, since net repair does not only imply costs for material, but also loss of active fishing time. If net replacement is too expensive, fishers may be obliged to fish with damaged gear that can become ineffective, reducing catch. Evaluating the impact of bycatch mortality on cetacean populations is also difficult, because a good knowledge of population status is required, which usually is hard to obtain (Murphy *et al*., 2009).

1.2 STUDY AREAS

Cetacean-fishery interactions were analysed in Iberian Atlantic waters, off Northern Spain and Portugal mainland, and in international waters of the South West Atlantic, off the Falkland Islands, where Spanish longliners target Patagonian toothfish (*Dissostichus eleginoides*) (Figure 1.1).

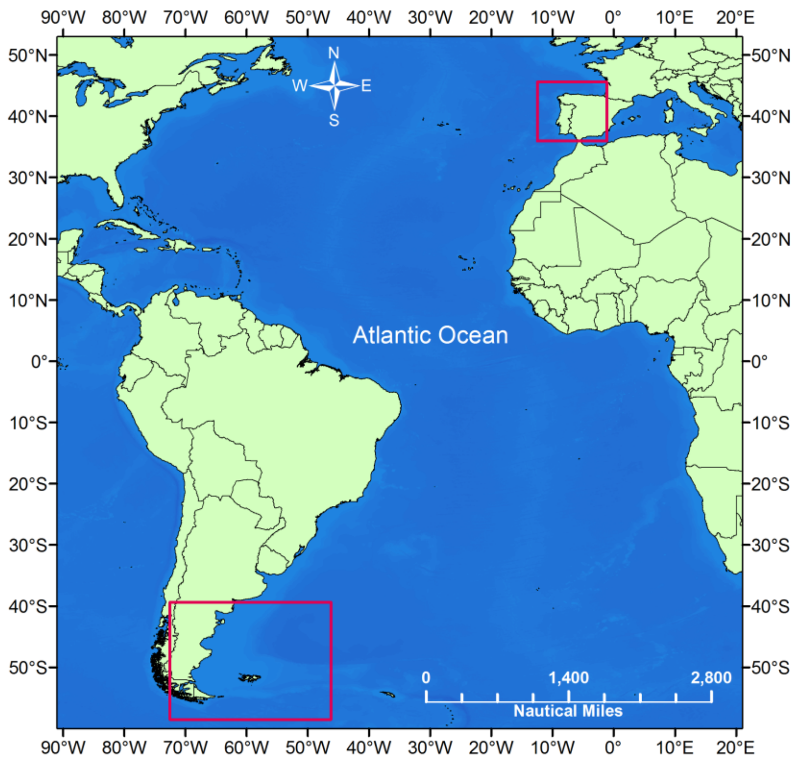

Figure 1.1. Study areas in Atlantic waters. The *pink square* indicates the geographic location of both study areas.

The Iberian Atlantic coastal margin is characterized by a relatively narrow continental shelf, with some wider sections between the Miño river (41°54'N) and the Nazaré Canyon (39°36'N) and in the eastern part of the Gulf of Cádiz (Figure 1.2). Rocky shores, which are interrupted by extensive sandy beaches in Northern Portugal and in the eastern part of the Algarve region, dominate the coastline. Galicia is the most irregular sector of the Iberian Peninsula due to the presence of a series of coastal inlets called "rías", the northern Galician rías being smaller and, due to their orientation and the absence of sheltering islands, much more exposed to the oceanic influence than the southern Galician rías (Figueiras *et al*., 2002; ICES, 2011a).

Several special marine landscapes can be found in the area, including: three highly biodiverse seamounts (Piñeiro *et al*., 2001; Sánchez *et al*., 2008; Taranto *et al*., 2012), namely the Le Danois Bank "El Cachucho" (44°4'N/5°5'W), the Galicia Bank (42°22'N/11°45'W) and the Gorringe Ridge (36°38'N/11°18'W); and the Nazaré Canyon, one of the largest submarine canyons in the world (maximum depth 5000 m) (Figure 1.2).

Coastal seasonal upwelling produced by northerly winds is primarily observed along the West Iberian coast and leads to the ascent of cold, nutrient-rich water to the surface, enhancing productivity in this area (Wooster *et al*., 1976; Fiúza, 1983; Álvarez Salgado *et al*., 1993). In the Southern Bay of Biscay and in the Gulf of Cádiz, coastal upwelling is weak, decreasing in intensity towards the east (Fiúza, 1983; Botas *et al*., 1990; Lavín *et al*., 1998).

The dominant fish species in the region comprise blue whiting (*Micromesistius poutassou*), European sardine (*Sardina pilchardus*), Atlantic mackerel (*Scomber scombrus*), horse mackerel (*Trachurus* spp), European anchovy (*Engraulis encrasicolus*), European hake (*Merluccius merluccius)*, boarfish (*Capros aper*), longspine snipefish (*Macroramphosus scolopax*) and several species of sparids (Sousa *et al*., 2005; ICES, 2011a; Santos *et al*. In Press a). Sousa *et al*. (2005) found a north-south gradient in the Portuguese marine community conditioned by differences in coastal morphology and oceanographic conditions, the Nazaré Canyon being the latitudinal boundary. In north-western and northern Spanish shelf waters, Santos *et al.* (In Press a) indentified clear spatial patterns in the occurrence of anchovy, with higher abundance near the French and Portuguese borders.

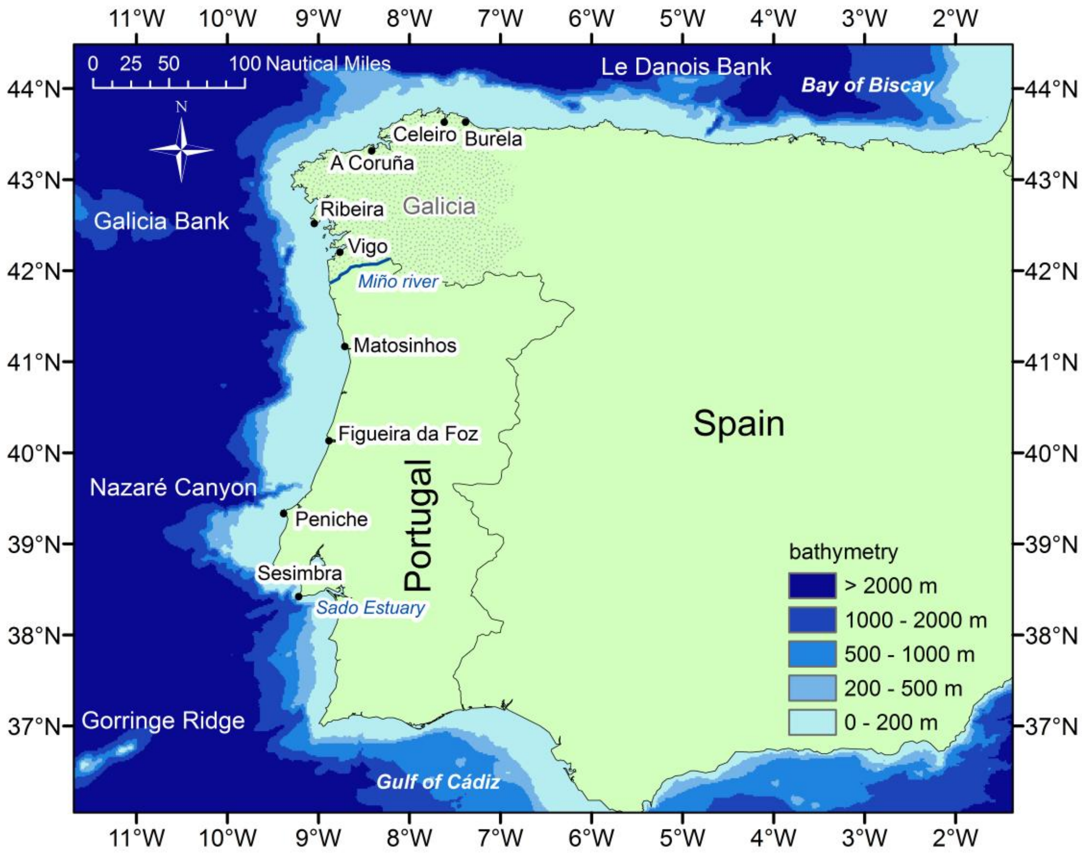

Figure 1.2. Map of the study area in Iberian Atlantic waters. The most important fishing harbours (in terms of total annual landings), special marine landscapes and the main bathymetry are indicated.

The Falkland Islands (Islas Malvinas) are located over the extensive Patagonian shelf, which is one of the widest continental shelves in the world (Heilemann, 2008; Figure 1.3). The Patagonian Sea is dominated by two marine currents: the cold, nutrient-rich Malvinas Current that derives from the Antarctic Circumpolar Current and moves northwards along the Argentine coast, and the warm, nutrient-poor, Brazil current that flows southwards along the continental shelf edge. Both currents meet in the so-called Confluence Zone (30 - 46°S), forming eddies and marine fronts (Acha *et al.*, 2004). This Confluence Zone, together with the terrestrial outflow of the Río de la Plata, and the shallow water depth of the area make the Patagonian Shelf one of the world's most productive marine systems (Heilemann, 2008). The area shows a high biological diversity of warm-, temperate- and cold-water species and is rich in fisheries resources. Fisheries in Patagonian waters mostly target Argentine hake (*Merluccius hubbsi*), Argentine shortfin squid

(*Illex argentinus*), southern blue whiting (*Micromesistius australis*), Patagonian grenadier (*Macruronus magellanicus*), and prawn (*Pleoticus muelleri*) (Heilemann, 2008).

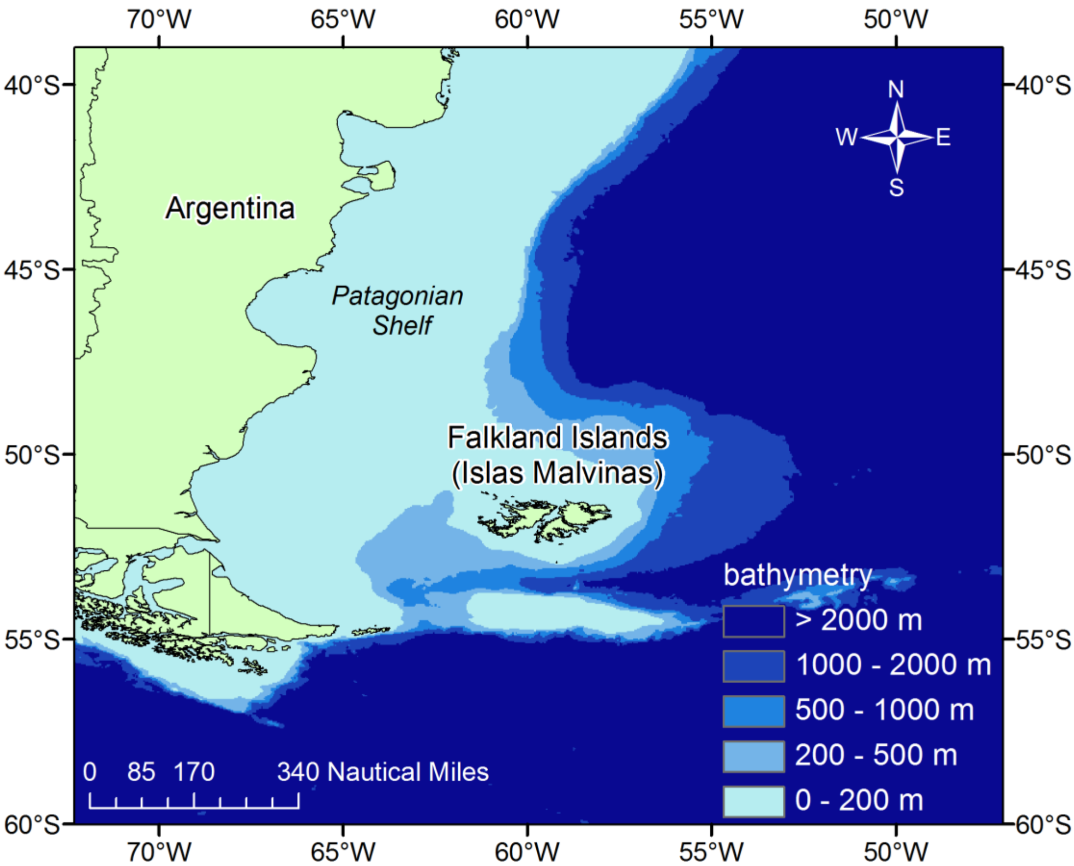

Figure 1.3. Map of the study area in South West Atlantic waters, around the Falkland Islands. The main bathymetry is indicated.

1.3 SPANISH AND PORTUGUESE FISHERIES

Spain and Portugal are both countries with a long fishing tradition (Scearce, 2009). Today, the Spanish fishing fleet is the largest within the European Union in terms of total tonnage and value of landings (EUROSTAT, 2010), with almost one-half of its landings being registered in the autonomous region of Galicia (Spanish Ministry of Agriculture, Food and Environment, 2013a). Fisheries are one of the most important components of the Galician economy, not only as a direct source of employment, but also as the driving force associated with industrial activity (Vázquez Seijas, 1998), contributing about 2% to the Galician gross domestic product (Galician Ministry of

Fisheries, 2010). Portugal has the highest per capita consumption of fishery products within the European Union (Failler, 2007), fishery products representing about 14% of consumer expenditure on foodstuffs, and providing 23% of the domestic animal protein supply. Although the fishing industry contributes less than 1% to the Portuguese gross national product, it is of great socio-economic importance for small coastal communities (FAO, 2013a).

In 2011, the Galician fishing fleet comprised 4734 boats, registered in 128 fishing harbours along the coast, Vigo, Ribeira, A Coruña, Burela and Celeiro being the most important in terms of landings (each of these harbour accounted for > 10% of total annual landings in Galicia in 2011; Galician Ministry of Fisheries, 2013). Along the Portuguese mainland coast there are 138 harbours, the majority of them being of small importance. The most important landing sites (i.e. each harbour accounting for > 10% of annual landings in Portugal mainland in 2011; Portuguese Institute for Statistics, 2013) are Matosinhos, Sesimbra, Peniche and Figueira da Foz (Figure 1.2). The Azores and Madeira Islands also contribute a considerable proportion to total Portuguese landings (9.8% and 2.7%, respectively). In 2011, 8380 fishing boats were officially registered in Portugal (7112 in Portugal mainland, 824 in the Azores and 444 in Madeira). Of the fishing boats registered in Portugal mainland, only 4010 have operational licenses to fish in Portuguese continental waters (Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2011; Portuguese Institute for Statistics, 2013).

1.3.1 COASTAL FISHERIES

Small-scale vessels (< 12 m) make up the bulk of the Galician and Portuguese fleet (87.7% and 90.3% of registered vessels, respectively) (Galician Ministry of Fisheries, 2013; Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2013). This fraction of the fleet fishes in coastal waters with minor gears including several types of artisanal gillnets, beam trawls, bottom-set longlines, traps, seine nets and dredges, targeting a large variety of fish, crustaceans and molluscs. Many of these vessels are classified as "polyvalent", i.e. change the fishing gear seasonally or use two or more gears simultaneously in the same area.

In Portugal, the majority (76%) of the polyvalent artisanal fleet operates in inland waters, such as estuaries and coastal lagoons, while only 24% deploy their gears in coastal marine waters. Moreover, there is also a small number (n=299) of polyvalent vessels of > 12 m.

Coastal gillnets can be subdivided into single panel bottom-set gillnets, driftnets and trammel nets, the first two consisting of a single netting wall and the latter of three parallel layers of netting. Usually several net panels are fastened together in a row, the maximum net length being limited to 4.5 km.

Single panel bottom-set gillnets have mesh sizes of 60 - 80 mm. They are not very selective, catching many different species of fish and cephalopods, inter alia European hake, red mullet (*Mullus surmuletus*), pouting (*Trisopterus luscus*), megrim (*Lepidorhombus* spp), white seabream (*Diplodus sargus*), skates (*Raja* spp), thickback sole (*Microchirus* spp), wedge sole (*Dicologlossa cuneata*) and common cuttlefish (*Sepia officinalis*).

Driftnets (mesh size: 23 – 40 cm) are mainly used to target shoaling pelagic fish such as European sardine, Atlantic mackerel, horse mackerel, European anchovy and bogue (*Boops boops*). Being connected with the operating vessel, the net is left free to drift with the current, usually near the surface. The maximum permitted net length for artisanal driftnets is 1 km.

Trammel nets consist of a slack central net with a small mesh size that is sandwiched between two taut outer nets with a much larger mesh. Depending on mesh size and fishing depth, they are used to catch many different species of fish, cephalopods and crustaceans, including flatfish (e.g. common sole *Solea solea*, turbot *Psetta maxima*, European plaice *Pleuronectes platessa*), wrasses (e.g. ballan wrasse *Labrus bergylta*), seabreams (e.g. white seabream, blackspot seabream *Pagellus bogaraveo*), European seabass (*Dicentrarchus labrax*), horse mackerel, European hake, whiting (*Merlangius merlangus*), monkfish (*Lophius* spp), skates, common octopus (*Octopus vulgaris*), spinous spider crab (*Maja squinado*), edible crab (*Cancer pagurus*), common spiny lobster (*Palinurus elephas*), European lobster (*Homarus gammarus)* and velvet swimcrab (*Necora puber*).

Artisanal bottom beam trawls are used to catch flatfish (e.g. sole and plaice) and crustaceans on the seabed. They are held open horizontally by a wood or metal beam.

Artisanal bottom-set longlines (maximum length: 4 km; up to 1700 hooks) are normally set at dawn and left to soak overnight. This fishery is mainly directed at European conger (*Conger conger*), black scabbardfish (*Aphanopus carbo*), blackspot seabream, pollack (*Pollachius pollachius*), European seabass, common dentex (*Dentex dentex*) and turbot.

Traps and pots are used to catch cephalopods (e.g. common cuttlefish and common octopus), crustaceans (e.g. common spiny lobster, velvet swimcrab, spinous spider crab) and fish (e.g. pouting). They are made from various materials (wood, wicker, metal rods, and wire netting) and have the form of cages or baskets with one or more entrances. Some types of traps are baited. They are usually set and left to soak on the seafloor close to the coast, either singly or in rows. Another type of trap is the so-called "alcatruz", which is a clay pot used by Portuguese fishers to target common octopus - mainly in the Algarve, Santa Luzía (close to Tavira) being the most important harbour for this gear.

Beach – and boat seine nets are composed of two long wings and a central bag and are normally launched from a boat, targeting coastal cephalopods (common octopus, common cuttlefish, European squid *Loligo vulgaris*) and fish (pouting, European sardine, horse mackerel and Atlantic mackerel).

Boat- and hand dredges are primarily used to harvest shellfish, such as scallops (Pectinidae), oysters (Ostreidae), mussels (Mytilidae), cockles (Cardiidae) and Venus clams (Veneridae) on the seabed. The dredges consists of a net bag or metal basket mounted on a frame of variable shape or size, the lower part of which carries a scraper blade that is sometimes toothed. The dredges are either towed by a steel wire rope to the boat or pulled behind by hand

(Source: Galician Ministry of Fisheries, 2013; Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2013).

1.3.2 PURSE SEINE FISHERIES

Portuguese and Galician purse seine vessels (vessel length between 12 – 24 m) also operate in national waters close to the coast, mainly targeting shoaling pelagic fish (European sardine, Atlantic mackerel, horse mackerel and European anchovy). Fishing trips do normally not exceed 24 hours. During the summer months, part of the Galician purse seine fleet moves to the fishing grounds of the Bay of Biscay to fish anchovy. In Portuguese fisheries sardine catches constitute around 40% of total landings (Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2013).

1.3.3 OFFSHORE FISHERIES

Large-scale offshore fisheries (vessel length > 18 m) operating bottom trawls, bottom and surface longlines and large single panel bottom-set gillnets, make up less than 10% of the Galician and Portuguese fleets (9% and 7.9% of registered vessels, respectively). This fraction of the fleet fishes in national and European waters (mainly off France, Ireland and Norway), but also in distant waters (around 2.5% of the Galician and Portuguese fleet) of the South West Atlantic (around the Falkland Islands), North West Atlantic (Flemish Cap, off Newfoundland, Greenland), Central - and South East Atlantic (off Morocco, Western Sahara, Mauritania, Cape Verde, Senegal, Guinea-Bissau, Ivory Coast, Angola and Namibia) and the Indian Ocean (off Somalia, Seychelles, Madagascar) (Galician Ministry of Fisheries, 2010; Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2013).

Bottom otter- and pair trawls are mainly used to catch demersal species, such as blue whiting, Atlantic mackerel, horse mackerel, European hake, angler (*Lophius piscatorius*) and megrim, but also common octopus and crustaceans (Norway lobster *Nephrops norvegicus*, blue and red shrimp *Aristeus antennatus* and deep-water rose shrimp *Parapenaeus longirostris*). The trawlers usually fish over the continental shelf, performing fishing trips of 1 - 10 days.

Longlines are usually set in the water for periods ranging from a few hours to several days. While surface longlines mainly target pelagic sharks, swordfish (*Xiphias gladius*) and tunids, bottom-set longlines are used to catch demersal fish, such as European hake, European conger, forkbeard (*Phycis* spp) and Patagonian toothfish. Industrial longlines have a maximum length of 20 km and can carry up to 6000 hooks.

Large-scale single panel bottom-set gillnets are up to 11 km long and are prohibited in shallow waters (< 50m). They are usually set at depth of 100-800 m, targeting European hake and monkfish. Accompanying species are pouting, rays, red scorpionfish (*Scorpaena scrofa*) or lobster.

A detailed description and a multilingual list of the fishing gears (Table A.1) and fisheries resources (Tables B.1 – B.3) dealt with in this thesis can be found in Appendices A and B.

1.4 CETACEAN SPECIES IN IBERIAN AND PATAGONIAN ATLANTIC WATERS

At least 21 species of cetaceans have been recorded in Galician waters (Penas Patiño and Piñeiro Seage, 1989; López el al., 2003; López, 2006) and 25 species off Portugal (Vingada et al., 2011; J. Vingada, Pers. Com.; see also Santos Reis and Mathias, 1996 and Brito *et al*., 2009), the most abundant being short-beaked common dolphin (*Delphinus delphis*), hereafter called "common dolphin". Off Galicia, the common bottlenose dolphin (*Tursiops truncatus*), hereafter called "bottlenose dolphin", is the second most frequently sighted species, while striped dolphin (*Stenella coeruleoalba*) is the second most abundant cetacean species off Portugal. Other species present include long-finned pilot whale (*Globicephala melas*), harbour porpoise (*Phocoena phocoena*), Risso's dolphins (*Grampus griseus*), and other large toothed (sperm whale *Physeter macrocephalus* and killer whale *Orcinus orca*) and baleen whales (Sequeira *et al*., 1996; López *et al*., 2002, 2004; Kiszka *et al*., 2007; Wise *et al*., 2007; Brito *et al*., 2009; Pierce *et al*., 2010; ICES, 2011a; Spyrakos *et al*., 2011; Vingada *et al*., 2011; Santos *et al*., 2012). In Patagonian Atlantic waters, 34 species of cetaceans (seven species of mystecetes and 27 species of odontocetes) can be found (Miloslavich *et al*., 2011), the most abundant being long-finned pilot whale, sperm whale, strap-toothed whale (*Mesoplodon layardii*) and Commerson's dolphin (*Cephalorhynchus commersonii*) (Oatley, 2012).

For a multilingual list of cetacean species, see Table B.4, Appendix B.

1.4.1 SHORT-BEAKED COMMON DOLPHIN (*DELPHINUS DELPHIS*) (LINNAEUS, 1758)

Body size: 1.6 - 2.0 m
Body mass: up to 200 kg

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Delphinus delphis is widely but discontinuously distributed in warm temperate and tropical waters of the Atlantic and Pacific Oceans, usually in areas where surface water temperature ranges from 10°C - 20°C. Common dolphins are often found in large schools of up to 10 000 animals (Carwardine, 1995; Rice, 1998). In Iberian Atlantic waters, the species mostly occurs over deep shelf waters (> 180 m), where it feeds on mesopelagic fish, such as blue whiting, (Robles, 1970; Whitehead *et al*., 1989; Santos *et al*., 2013), but also frequently enters coastal waters (Méndez Fernández *et al*., 2012) to prey on shoaling pelagic fish such as horse mackerel, European sardine and European anchovy (Silva, 1999; Pusineri *et al*., 2007; Méndez Fernández *et al*., 2012; Santos *et al*., 2013). Co-operative feeding techniques are sometimes used to herd fish schools (Silva, 1999).

1.4.2 COMMON BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*) (MONTAGU, 1821)

Body size: 2.0 – 3.8 m
Body mass: 200 - 500 kg

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Bottlenose dolphins are primarily found in coastal and inshore regions of tropical and temperate waters of the world, but also in pelagic waters. Population density seems to be higher nearshore (Wells and Scott, 1999). Group size is usually around 2-15 animals, but large herds of several hundred to a thousand are regularly seen offshore (Wells and Scott, 2009) Coastal dolphins frequently enter sheltered, shallow areas such as estuaries, bays, lagoons and river mouths (dos Santos and Lacerda, 1987; Miller and Baltz, 2009). Bottlenose dolphins primarily feed individually, although co-operative herding of fish schools has been reported. In Iberian Atlantic waters, coastal *Tursiops* feed on a large variety of fish (e.g. silvery pout *Gadiculus argenteus,* mullet *Mugil* spp, pouting, European conger, horse mackerel, European sardine) and cephalopods, while blue whiting and European hake are the main prey of offshore *Tursiops* (Santos *et al*., 2007; Fernández *et al*., 2011a; Sollmann, 2011).

1.4.3 LONG-FINNED PILOT WHALE (*GLOBICEPHALA MELAS*) (TRAILL, 1809)

Body size: 5.5 – 6.5 m
Body mass: 1300 – 2300 kg

Long-finned pilot whales can be found in cold temperate and subpolar regions of all oceans at temperatures of 0 - 25°C (Martin, 1994), typically in deep offshore waters (Rice, 1998). They are highly social, forming pods of 110-1200 individuals (Zachariassen, 1993; Bloch, 1998). The species is primarily teuthophagous, but will also take small medium-sized gregarious fish, when available (Jefferson *et al*., 1993). In Iberian Atlantic waters *G. melas* exploits oceanic, as well as neritic foraging areas, feeding on several species of cephalopods and fish (Santos *et al*., 1996; Kiszka *et al*., 2007; Spitz *et al*., 2011; Méndez Fernández *et al*., 2012; Santos *et al.*, In Press b).

1.4.4 HARBOUR PORPOISE (*PHOCOENA PHOCOENA*) (LINNAEUS, 1758)

Body size: 1.5 – 1.6 m
Body mass: 50 - 60 kg

Harbour porpoises are found in cool temperate and subpolar waters of the Northern Hemisphere (Jefferson *et al*., 1993), mostly within shelf waters (Sequeira, 1996; Kiszka *et al*., 2007; Pierce *et al*., 2010; Spyrakos *et al*., 2011; Méndez Fernández *et al*., 2012). Being comparatively small and shy, the animals are difficult to detect, even under calm sea conditions (Embling *et al*., 2010). They usually aggregate into small groups (< 8 animals), but may also form large, loose groups of 50 to several hundred animals, mostly for feeding or migration (Jefferson *et al*., 1993). *P. Phocoena* feeds on a large variety of fish and cephalopods, the main prey items varying on regional and seasonal scales (Jefferson *et al*., 1993). Along the Northern Spanish Atlantic coast, the species preys on both benthic coastal and offshore prey species (Spitz *et al*., 2006a; Read *et al*., 2012).

1.4.5 STRIPED DOLPHIN (*STENELLA COERULEOALBA*) (MEYEN, 1833)

Body size: 2.2 – 2.4 m
Body mass: up to 156 kg

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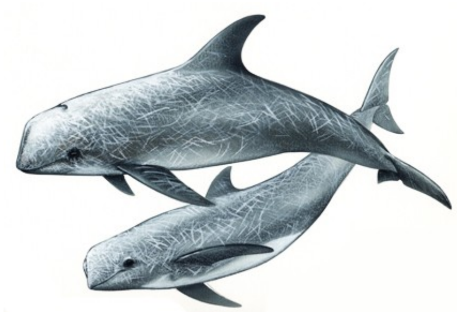
The striped dolphin is distributed in tropical and temperate waters all around the world. It is considered an oceanic species that prefers deep water over the continental shelf edge and slope (Perrin *et al*., 1994; Rice, 1998). Schools are of varying size. In the Bay of Biscay, for instance, group size ranges from 1 - 250 animals (Kiszka *et al*., 2007). In Iberian Atlantic waters, *S. coeruleoalba* mainly feeds on cephalopods, but also on fish in mesopelagic, neritic and coastal areas (Kiszka *et al*., 2007; Sollmann, 2011; Spitz *et al*., 2006b, 2011; Méndez Fernández *et al*., 2012).

1.4.6 RISSO'S DOLPHIN (*GRAMPUS GRISEUS*) (CUVIER, 1812)

Body size: up to 3.8 m
Body mass: up to 500 kg



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Risso's dolphins are widely distributed from the tropics through the temperate regions of all oceans (Jefferson *et al*., 1993). They mainly inhabit deep oceanic and continental slope waters (Baird, 2002). The patchy distribution and local abundance of this species is probably related to its enhanced feeding activity in productive marine regions, such as upwelling areas (Kruse *et al*., 1999). Group size tends to be small to moderate (1 - 100 individuals), averaging 30 animals. *G. griseus* is known to be exclusively teuthophagous (Clarke and Pascoe, 1985), preying on a mixture of neritic, oceanic, and occasionally bottom-dwelling cephalopods (Kruse *et al*., 1999; MacLeod *et al.*, In Press).

1.4.7 SPERM WHALE (*PHYSETER MACROCEPHALUS*) (LINNAEUS, 1758)

Body size: 11- 21 m
Body mass: up to 15 000 – 57 000 kg

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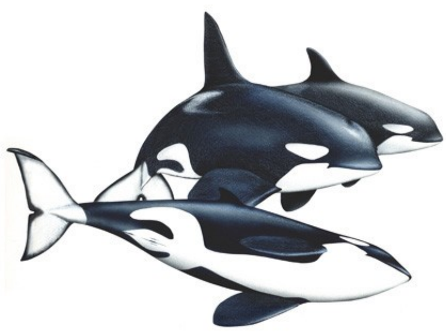
Sperm whales have a circumglobal distribution, from polar to tropical regions, concentrating in deep water with high marine productivity (Rice 1989; Whitehead, 2009).Their social organization is complex, with groups of young males ("bachelor" groups in different stages of sexual maturation) and solitary sexually mature males spending most of the year separated from groups of females and calves, migrating to higher latitudes in spring/summer and returning to lower latitudes in winter; females and calves remain in low latitudes year-round (Berzin, 1971). The animals spend more than 72% of their time in foraging dive cycles, repeatedly performing long dives of about 45 minutes (modal depth = 985 m in the Atlantic Ocean; Watwood *et al*., 2006), preying on deep-sea cephalopods of various sizes, and to a lesser extent on fish (Kawakami, 1980; Rice, 1989; Santos *et al*., 1999).

1.4.8 KILLER WHALE (*ORCINUS ORCA*) (LINNAEUS, 1758)

Body size: up to 7.7 – 9 m
Body mass: 4 700 – 6 600 kg



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Orcinus orca is a cosmopolitan species in all oceans and climate zones, being most abundant in coastal waters and cooler regions with high productivity (Jefferson *et al*., 1993; Dahlheim and Heyning, 1999). The species is mainly found in deep oceanic waters, but it can also enter shallow bays, inland seas, and estuaries (Carwardine, 1995). Pod size usually ranges from 1 - 55 animals. Killer whales are opportunistic predators feeding on broad spectrum of fish and marine mammals, although local populations can be specialised in certain prey types (Ford, 2009). In North East Atlantic waters, Atlantic mackerel and Atlantic herring (*Clupea harengus*) are important prey species (Foote *et al*., 2012), while in the Strait of Gibraltar, killer whales prey on migrating northern bluefin tuna (*Thunnus thynnus*) (Guinet *et al*., 2007).

1.5 THREATS TO CETACEANS AND CONSERVATION POLICY

There is a variety of factors that threaten cetaceans and their long-term conservation, including climate change, environmental contaminants, marine debris, harmful algal blooms, anthropogenic sound, habitat degradation, ecotourism and aboriginal harvests (Reynolds *et al*., 2009). Fishery-related mortality, however, is considered one of the major threats to cetaceans worldwide (IWC, 1994; Kaschner 2003; Young and Iudicello, 2007).

Measures for the conservation of cetaceans and their habitats are specified and regulated in several regional, national and international agreements (for an overview see Table 1.1).

Globally cetaceans are protected under the CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora; enforcement in 1975) and CMS (Convention on the Conservation of Migratory Species of Wild Animals; enforcement in 1983) Conventions, which are both intergovernmental treaties.

CITES aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival. **Sperm whales** are listed under Appendix I (species threatened with extinction) and **all other cetacean species** are included in Appendix II (species not threatened with extinction, but in danger if their commerce is not subject to restraints).

The objective of CMS is the conservation of terrestrial, aquatic and avian migratory species throughout their range. The s**perm whale** and the Mediterranean population of **common dolphin** are listed under Appendix I (migratory species threatened with extinction). CMS Parties strive towards strictly protecting these animals, conserving or restoring the places where they live, mitigating obstacles to migration and controlling other factors that might endanger them. Besides establishing obligations for each State joining the Convention, CMS promotes concerted action among the Range States. All cetacean species covered in the present work are listed under Appendix II (migratory species that need or would significantly benefit from international co-operation), either in their whole distribution range, or separate regional populations. Range States are encouraged to conclude global or regional conservation agreements.

On the European level, the Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats; enforcement in 1982) aims to ensure the conservation and protection of wild plant and animal species (listed in four appendices) and their natural habitats, to increase co-operation between parties, and to regulate the exploitation of the listed species. **All cetacean species** considered in the present work are included in Appendix II (strictly protected fauna species).

To implement the Bern Convention in Europe, the European Community adopted the Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (the EC Habitats Directive) in 1992. The main aim of the Habitats Directive is to promote the maintenance of biodiversity by requiring Member States to take measures to maintain or restore natural habitats and wild species listed in the Annexes to the Directive at a favourable conservation status, introducing robust protection for those habitats and species of European importance. **All cetaceans** are included in Annex IV, identifying them as species of European Community interest in need of strict protection, prohibiting all forms of deliberate capture and killing, damage to or destruction of breeding or resting sites, disturbance, particularly during the period of breeding, and the possession of, and internal trade in these animals. Under Annex II, **bottlenose dolphin** and **harbour porpoise** are listed as species requiring the designation of Special Areas of Conservation (SACs). The Directive led to the creation of a Europe-wide network of Special Areas of Conservation called "Natura 2000".

The EC Council Directive 56/2008 (Marine Strategy Framework Directive)[1], which was adopted in 2006, seeks to achieve "good environmental status" for the marine areas within the EU by 2020. This implies, inter alia, that marine ecosystems can withstand anthropogenic change, and that habitats and species (including cetaceans) are protected. Member states are required to develop a marine strategy for their national waters, encompassing a clear assessment of their current environmental status and a targeted programme of measures to be introduced by 2016.

ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas; enforcement in 1994) and ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area; enforcement in 2001) are regional agreements concluded under the auspices of the Convention on the Conservation of Migratory Species of Wild Animals (CMS). Both agreements aim to achieve and maintain a favourable conservation status for cetaceans.

[1] **Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008** establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)

ASCOBANS and ACCOBAMS Member States are obliged to bring into force measures for habitat conservation and management, promote scientific research, evaluate bycatch and strandings data, improve legislation and raise public awareness of cetacean conservation. This also includes the monitoring of cetacean-fishery interactions and the designation of "areas of special importance" for breeding and feeding. ACCOBAMS covers **all cetacean species** occurring in its agreement area, while ASCOBANS covers **all species of toothed whales**, except the sperm whale. The North West Iberian Peninsula lies within the ASCOBANS range, but Spain and Portugal have not signed the agreement yet, although both are Parties to ACCOBAMS.

On the national level, both Spain and Portugal have established specific legal measures for the protection of cetaceans and their habitats in their territorial waters (Decreto-Lei 263/1981[2] [Portuguese legislation]; Real Decreto 1727/2007[3] [Spanish legislation]). In addition, cetaceans are also mentioned in the Spanish national legislation established to protect the environment and biodiversity (Ley 42/2007 de Protección del Patrimonio Natural y la Biodiversidad[4]) and specifically for the marine environment (Ley 41/2010 de Protección del Medio Marino[5]).

[2] **Decreto-Lei 263/1981, de 3 de Setembro.** Regulamento de Protecção dos Mamíferos Marinhos na Zona Costeira e Zona Económica Exclusiva Continental Portuguesa

[3] **Real Decreto 1727/2007, de 21 de diciembre** por el que se establecen medidas de protección de los cetáceos

[4] **Ley 42/2007, de 13 de diciembre,** del Patrimonio Natural y de la Biodiversidad

[5] **Ley 41/2010, de 29 de diciembre,** de Protección del Medio Marino

Table 1.1. Regional, national and international agreements including conservation measures for cetaceans: geographic coverage and listed species

Name of agreement	Coverage	Appendices and species	Common dolphin	Bottlenose dolphin	Long-finned pilot whale	Harbour porpoise	Striped dolphin	Risso's dolphin	Sperm whale	Killer whale
CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora)	World ocean	Appendix I: Species threatened with extinction							yes	
		Appendix II: Species in danger of extinction, if their commerce is not controlled	yes	yes	yes	yes	yes	yes		yes
CMS or Bonn Convention (Convention on the Conservation of Migratory Species of Wild Animals)	World ocean	Appendix I: Migratory species threatened with extinction	yes[1]						yes	
		Appendix II: Migratory species in need of international co-operation	yes[2]	yes[3]	yes[4]	yes[5]	yes[6]	yes[7]	yes	yes
Bern Convention (Convention on the Conservation of European Wildlife and Natural Habitats)	European seas	Appendix II: Strictly protected fauna species	yes	yes	yes	yes	yes	yes	yes	yes
EC Habitats Directive (Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora)	EC waters	Annex II: Species requiring designation of Special Areas of Conservation (SACs)		yes		yes				
		Annex IV: Species of community interest in need of strict protection	yes	yes	yes	yes	yes	yes	yes	yes
EC Marine Strategy Framework Directive	EC waters	Each member States is required to select species to be protected for its marine waters								
ASCOBANS (Agreement on the Conservation of Small Cetaceans of the Baltic, NE Atlantic, Irish and North Seas)	Baltic & North Seas, NE Atlantic area delimited by the shores of the Gulfs of Bothnia & Finland	All toothed whales in agreement area, except sperm whale	yes	yes	yes	yes	yes	yes		yes
ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black & Mediterranean Seas and Contiguous Atlantic Area)	Mediterranean & Black Seas, Atlantic area west of the Strait of Gibraltar	All cetacean species in the agreement area	yes	yes	yes	yes	yes	yes	yes	yes

[1] Mediterranean population, [2] North and Baltic Sea, Mediterranean, Black Sea & Eastern tropical Pacific populations, [3] North Sea, Baltic Sea, Mediterranean & Black Sea populations, [4] North and Baltic Sea populations, [5] North and Baltic Sea, NW Atlantic, Black Sea & NW African populations, [6] Eastern tropical Pacific & Mediterranean populations, [7] North Sea, Baltic Sea & Mediterranean populations

1.6 AVAILABLE INFORMATION ON INTERACTIONS OF CETACEANS WITH SPANISH AND PORTUGUESE FISHERIES

Several species of cetaceans are reported to interact with Spanish and Portuguese fishing vessels in national and international waters.

Bottlenose dolphins are frequently mentioned to prey on artisanal gillnets and longlines in coastal waters, causing damage to catch and gear. In distant Atlantic offshore waters, sperm whales, false killer whales (*Pseudorca crassidens*) and killer whales are described to remove fish from large-scale longlines, reducing catch rates.

Common dolphin, striped dolphin, harbour porpoise and long-finned pilot whales are the species mainly bycaught (particularly in set gillnets and pelagic trawls). Bycatch rates, particularly of vulnerable species such as the harbour porpoise, were suggested to be potentially unsustainable in Iberian Atlantic waters (Sequeira, 1996; López *et al*., 2003; Read *et al.*, 2012).

1.6.1 GILLNETS

Reports by fishers in Galicia (NW Spain) suggest that bottlenose dolphins take prey from artisanal coastal gillnets, frequently tearing holes into the nets while they attempt to remove the fish (Aguilar, 1997; López *et al*., 2003). In Balearic waters, Brotons *et al*., 2008a and Gazo *et al*., 2008 reported significant reductions of catch rates and net damage caused by bottlenose dolphins preying on trammel nets, leading to estimated economic loss of 6.5% of the total landed catch value (Brotons *et al*., 2008a) , corresponding to € 1094 per trammel net boat each season (Gazo *et al*., 2008).

Common dolphin is the species most frequently bycaught in set gillnets off the Northern Spanish (Nores *et al*., 1992; López *et al*., 2003) and Portuguese (Silva and Sequeira, 2003) Atlantic coasts. In Galician waters, set offshore gillnets seem to be a major cause of common dolphin mortality, while bottlenose dolphin and harbour porpoise, due to their coastal distribution, are more likely to get entangled in artisanal inshore gillnets (Aguilar, 1997; López *et al*., 2003). Along the Portuguese coast, common dolphin and harbour porpoises are also often bycaught in beach seines (Sequeira, 1996; Ferreira, 2007).

1.6.2 HOOK AND LINE FISHERIES

Off the Azores archipelago, depredation by bottlenose dolphins on fish hooked on bottom-set longlines and hand lines was reported by Prieto *et al*. (2005), Catarino (2006) and Silva *et al*. (2011). These authors calculated overall depredation rates (number of fishing sets with evidence of depredation) of 2 - 25%, but no significant reduction of catch rates was observed in any of the studies. Off South Georgia (SW Atlantic), Purves *et al*. (2004) found that killer whales and sperm whales take Patagonian toothfish from bottom-set longlines, potentially decreasing catch rates.

Interactions of false killer whales with surface longliners for swordfish in Atlantic waters have been described by Ramos Cartelle and Mejuto (2007), Hernandez Milian *et al*. (2008) and Silva *et al*. (2011). Overall depredation rates were low in these surveys (1 - 9% of sets), but when depredation occurred, up to 50% or even the whole catch were lost. The incidental mortality rate of false killer whales was estimated at 0.36 individuals per million hooks in Atlantic waters (Ramos Cartelle and Mejuto, 2007)

Silva *et al*. (2011) reported interactions of common dolphins, Atlantic spotted dolphins (*Stenella frontalis*) and bottlenose dolphins with Azorean pole-and-line fisheries for tuna. The authors described that tuna schools frequently sank in the presence of cetaceans and that cetaceans competed with tuna for live bait frequently, leading to a reduction of catch. Cetaceans, particularly common dolphins, were reported to get occasionally hooked and released alive by cutting the fishing line.

1.6.3 TRAWLS

Pelagic trawls (particularly pair trawls) are reported to incidentally catch common and striped dolphins off Galicia, particularly during nocturnal trawling. Usually 1-10 animals are caught per bycatch event. Long-finned pilot and sperm whales are also occasionally bycaught (Aguilar, 1997; López *et al*., 2003; Fernández Contreras *et al*., 2010). According to these authors, the survival rate of cetaceans trapped in trawl nets is close to zero.

Off Portugal, trawls account for 9% of common dolphin bycatch mortality (Silva and Sequeira, 2003).

1.6.4 PURSE SEINES

Wise *et al*. (2007) described interactions between common dolphins and purse seine fisheries in Portuguese waters. Based on observer and interview data, fish schools were observed to sink, scatter or cluster in the presence of dolphins in 4 - 12.3% of fishing events, without any significant effect on catch rates. The author suggested that, due to the low frequency of interactions, small cetaceans are not harmful to Portuguese purse seine fisheries. In Galician purse seine fisheries, common and striped dolphins are reported to interrupt or slow down the fishing activities and to scatter fish (Aguilar, 1997; López *et al*., 2003). All authors report that bycatch occurs frequently. Mortality rates are, however, assumed to be low since dolphins encircled in the net normally survive, either by escaping unaided or being helped to escape by fishers.

1.7 STRATEGIES TO MITIGATE CETACEAN-FISHERY INTERACTIONS AND THEIR IMPLEMENTATION IN EU COMMON FISHERIES POLICY

1.7.1 MITIGATION STRATEGIES

There are several measures to mitigate cetacean-fishery interactions, including changes in fishing practice as well as technical solutions (for a review see Werner *et al.*, 2006), the choice of which largely depends on the type of interaction, the characteristics of the fishery and the cetacean species involved.

The Eastern Tropical Pacific purse seine fishery for tuna is probably the best example of how only a few changes in fishing practice can dramatically reduce dolphin bycatch. Cetacean bycatch used to be major problem in this fishery during the 1960s (Francis *et al*., 1992) until an international long-term monitoring program coordinated by the Inter-American Tropical Tuna Commission (IATTC) introduced measures to reduce cetacean bycatch during the 1980s and 1990s. Since then, setting the net around dolphin schools was prohibited and the so-called "back-down" procedure was introduced to facilitate the escape of encircled dolphins. This procedure involves a reversing of the boat, causing the net shape to change from a circle to an oval, and then the net is pulled under the dolphins on the surface. These modifications lead to a 98% reduction of dolphin bycatch since the years of peak mortality, while the fishery has continued to operate successfully (Gosliner 1999; Hall and Donovan, 2002).

Tregenza (2001) suggested that operational interactions may occur less frequently if certain acoustic cues, such as the vessel motor and fishery equipment noise, are reduced to a minimum, since these noises are thought to attract cetaceans to the fishing gear (Barlow and Cameron, 2003; Lauriano *et al*., 2004).

Time/area restrictions, i.e. the prohibition or avoidance of fishing activities in a certain area or time of the day/year can be effective when interactions are predictable in time and space (Murray *et al*., 2000). This is for instance the case in the Galician pair trawl fishery, where dolphin bycatch occurs most frequently during nocturnal trawling around the continental shelf break, particularly during the summer months (Fernández Contreras *et al*., 2010).

Technical measures to mitigate cetacean-fishery interactions comprise gear modifications and the use of acoustic deterrent devices.

Acoustically reflective nets have been developed to reduce cetacean bycatch in gillnet fisheries. The addition of barium sulphate or iron oxide to the gillnet twine makes the nets more reflective to echolocation signals produced by cetaceans and consequently more easily detectable to the animals (Dawson, 1994; Mooney *et al*., 2007; Trippel *et al*., 2008).

The use of dolphin exclusion devices (Figure C.1, Appendix C) may help to reduce dolphin mortality in trawl fisheries, although the effectiveness of such devices has still not been completely assessed. The device consists of a widely spaced metal grid, placed in the extension piece of the trawl net. The angle of the grid deflects large animals, such as cetaceans, upwards to an escape hatch in the top of the trawl net, while fish continue through the grid into the cod-end (Northridge *et al*., 2003a).

Acoustic deterrent devices (ADDs), also called "pingers" (Figure C.2, Appendix C), are low intensity (generally < 150 dB re 1 mPa @ 1m) acoustic signal generators designed to keep cetaceans away from fishing gear by producing unpleasant high-frequency sounds in the hearing range of the cetaceans (Reeves *et al*., 2001). Pingers are primarily attached to static fishing gear and have been successfully used to reduce bycatch and cetacean depredation in set gillnet and driftnet fisheries (Barlow and Cameron, 2003; Brotons *et al*., 2008b; Gazo *et al*., 2008; Carretta and Barlow, 2011).

1.7.2 IMPLEMENTATION OF MITIGATION MEASURES IN EU COMMON FISHERIES POLICY

Within the EU Common Fisheries Policy, measures to mitigate cetacean-fishery interactions have widely been focussed on the reduction of cetacean bycatch.

Several regulations have been introduced to mitigate fisheries bycatch of non-target species (also including cetaceans), such as the EC Regulation 345/92[6] that restricts the length of driftnets to 2.5 km and EC Regulation 1239/98[7] that completely prohibited the use of driftnets to catch tunids, swordfish, sharks and other similar species by 2002.

In order to reduce incidental dolphin mortalities in the tuna purse seine fishery in the Eastern Pacific Ocean, the encircling of dolphin schools during the fishing process was prohibited in 2001 (EC Regulation 973/2001[8]).

Cetacean bycatch is specifically regulated through the EC Council Regulation 812/2004[9] implemented to monitor and reduce the incidental bycatch of cetaceans in certain fisheries. In compliance with the regulation, 10% of all vessels ≥ 15 m fishing with trawls (pelagic and high-vertical opening trawl nets) and set gillnets (single panel bottom-set gillnets, trammel nets and driftnets with mesh size ≤ 80 mm) in Iberian Atlantic waters are obliged to carry on-board observers. Vessels < 15 m have to be monitored by means of scientific surveys and pilot projects. The use of pingers is only obligatory for single panel bottom-set gillnet and trammel net fisheries that operate from vessels ≥ 12 m.

In addition, EC Regulation 199/2008[10] requires the monitoring of discards and bycatch, including cetaceans, in certain fisheries within Community waters.

[6] **Council Regulation (EEC) No 345/92 of 27 January 1992** amending for the eleventh time Regulation (EEC) No 3094/86 laying down certain technical measures for the conservation of fishery resources

[7] **Council Regulation (EC) No 1239/98 of 8 June 1998** amending Regulation (EC) No 894/97 laying down certain technical measures for the conservation of fishery resources

[8] **Council Regulation (EC) 973/2001 of 14 May 2001** laying down certain technical measures for the conservation of certain stocks of highly migratory species

[9] **Council Regulation (EC) 812/2004 of 26 April 2004** laying down measures concerning incidental catches of cetaceans in fisheries and amending Regulation (EC) 88/98

[10] **Council Regulation (EC) 199/2008 of 25 February 2008** concerning the establishment of a Community framework for the collection, management and use of data in the fisheries sector and support for scientific advice regarding the Common Fisheries Policy

1.8 THESIS AIM AND OBJECTIVES

The aim of the present work is to provide new insight into cetacean-fishery interactions in Iberian and distant Atlantic waters of interest to Spanish and Portuguese fisheries. Quantitative and qualitative research methods are used to assess different types of interactions, to determine their scale and to evaluate possible strategies for the mitigation of interactions on a case-specific level.

Objective 1. To assess the potential for cetacean-fishery interactions in the study area by relating cetacean occurrence patterns to local fishing activities.

Objective 2. To identify different types of cetacean-fishery interactions, the fisheries and cetacean species most involved, and fishing areas where these interactions mainly occur.

Objective 3. To quantify the extent of cetacean-fishery interactions and their consequences in terms of potential benefits and costs for cetaceans (bycatch mortality) and fisheries (reduction of catch, gear damage and associated economic loss).

Objective 4. To identify and evaluate methods for the mitigation of cetacean-fishery interactions, and to test the efficiency of some of these mitigation measures, including the assessment of possible side effects.

Objective 5. To compare the performance and reliability of different methodologies (interviews with fishers and on-board observations by skippers and fisheries observers) to assess and monitor cetacean-fishery interactions.

CHAPTER 2

Cetacean occurrence and habitat preferences in Iberian Atlantic waters

This chapter was submiited as paper to the journal "*Aquatic Conservation: Marine and Freshwater Ecosystems*" and is currently under revision.

Goetz, S., Read, F., Ferreira, M., Portela, J., Santos, B., Vingada, J., Siebert, U., Marçalo, A., Santos, J., Araújo, H., Monteiro, S., Caldas, M., Riera, M. and G.J. Pierce.
Cetacean occurrence and habitat preferences in Iberian Atlantic waters: results from co-operative research involving local stakeholders.

The main author's contribution to this publication included the coordination of the inter-institutional co-operation, survey and sampling design, data collection during the interview survey (data derived from vessel-based sightings were provided by fisheries observers and skippers), data processing and analysis, and publication writing.

2.1 ABSTRACT

Iberian Atlantic waters are heavily exploited by Spanish and Portuguese fisheries. Overlaps between fishery target species and cetacean diet, and between fishing areas and cetacean foraging areas, can lead to cetacean-fishery interactions including bycatch mortality of cetaceans. The designation of Special Areas of Conservation (SAC) for bottlenose dolphin (*Tursiops truncatus*) and harbour porpoise (*Phocoena phocoena*) under the EU Habitats Directive requires detailed knowledge of their abundance and distribution. The present study assesses cetacean distribution, habitat preferences and hotspots for cetacean-fishery interactions by using a co-operative research approach with stakeholder participation (fishers, fisheries observers, fisheries authorities, scientists), as well as the combination of different opportunistic sampling methods (interview survey, on-board observations). The performance of each survey method is also evaluated. Generalized linear models (GLM) and GIS maps were used to describe cetacean habitat preferences (geographic area, water depth, prey species) and spatial patterns of occurrence. Common dolphin (*Delphinus delphis*) and bottlenose dolphin were the most frequently sighted species, the former in waters >50 m, frequently in the vicinity of purse seines and trawls, and the latter particularly inside the South Galician rías and close to vessels operating further offshore in Portuguese waters. Harbour porpoise was seen over the whole continental shelf, often next to beach seines, while long-finned pilot whale (*Globicephala melas*) and striped dolphin (*Stenella coeruleoalba*) were mostly seen from vessels fishing offshore. Results suggest that cetacean occurrence is linked to prey distribution and that interactions with fisheries are most likely for common dolphins (offshore fisheries) and bottlenose dolphins (coastal fisheries). The survey methods were complementary and performed well, although sightings frequency for some cetacean species was biased by survey method. Opportunistic sampling has certain restrictions concerning reliability, but can cover a wide area at comparatively low cost and make use of local ecological knowledge (LEK) to yield information required for cetacean conservation.

2.2 INTRODUCTION

Iberian Atlantic waters are highly productive and rich in marine resources (Wooster *et al*., 1976), which are heavily exploited by Spanish and Portuguese fisheries. The Spanish fishing fleet is the largest within the European Union in terms of total tonnage and value of landings (EUROSTAT, 2010), with almost one-half of its landings being registered in Galicia (Spanish Ministry of Agriculture, Food and Environment, 2013a).

Several species of cetaceans can be found in Iberian Atlantic waters, the most abundant being short-beaked common dolphin (*Delphinus delphis*), common bottlenose dolphin (*Tursiops truncatus*) and striped dolphin (*Stenella coeruleoalba*). Other species present include long-finned pilot whale (*Globicephala melas*), harbour porpoise (*Phocoena phocoena*), Risso's dolphins (*Grampus griseus*) and other large toothed and baleen whales (Sequeira *et al*., 1996; López *et al*., 2002, 2004; Kiszka *et al*., 2007; Wise *et al*., 2007; Brito *et al*., 2009; Pierce *et al*., 2010; ICES, 2011a; Spyrakos *et al*., 2011; Vingada *et al*., 2011; Santos *et al*., 2012).

All the above-mentioned species are listed as in need of strict protection under the EU Habitats Directive (see **Section 1.5**), which prohibits all forms of deliberate capture and killing, as well as the disturbance of their breeding and resting sites. In addition, Annex II of the Directive lists bottlenose dolphin and harbour porpoise as priority species for conservation that require the designation of Special Areas of Conservation (SACs). In order to select suitable areas for cetacean conservation, detailed knowledge of cetacean habitat preferences is essential. The identification of the principal prey species and feeding grounds also facilitates the detection of hotspots for cetacean-fishery interactions, which may have a negative impact on cetacean populations through depletion of cetacean food resources (Bearzi *et al*., 2006) and incidental bycatch mortality (Read *et al*., 2006). Moreover, EU legislation such as the Habitats Directive specifies requirements for Member States to monitor and report on the status of cetacean populations. A fundamental part of this monitoring is gathering data on distribution and abundance.

There are many methodologies to assess cetacean abundance, distribution and habitat preferences, each with their respective strengths and weaknesses.

In Iberian Atlantic waters, dedicated, systematic cetacean surveys to determine abundance and/or distribution have been carried out by plane, ship and from land (Lens *et al*., 1989; Sanpera and Jover, 1989; Hammond *et al*., 2002; López *et al*., 2004; SCANS II, 2008; CODA, 2009; Pierce *et al*., 2010; Santos *et al.*, 2012). However, dedicated aerial and ship-based surveys are logistically complex and costly, while land-based surveys are clearly restricted to coastal waters. Scientists have therefore increasingly resorted to the use of opportunistically collected data, such as observations made from fishing vessels (López *et al*., 2004; Spyrakos *et al*., 2011), passenger ferries (Kiszka *et al*., 2007) and whale-watching boats (Moura *et al*., 2012), as well as using data derived from historical records (Brito *et al*., 2009; Brito and Vieira, 2010) and cetacean strandings (López *et al*., 2002; Silva and Sequeira, 2003). These alternative survey methods allow for the coverage of a wide range of marine habitats (coastal and offshore) at comparatively low cost, although data reliability is usually lower than for dedicated scientific surveys and sampling effort tends to be unquantified or unsystematic, especially if vessels with fixed routes are used as platforms of opportunity (Isojunno *et al*., 2012). Despite these limitations and due to the fact that international large-scale dedicated surveys are unlikely to be feasible more than once a decade, considerable effort has gone into developing protocols to allow data from small-scale and opportunistic surveys to be integrated into the evaluation of the status of cetacean populations, including the detection of trends in distribution and abundance (see Joint Cetacean Protocol; JNCC, 2013).

In addition, opportunistic surveys offer the opportunity to actively involve resource users, such as fishers, wildlife observers, seamen, etc., into data collection and make use of their local ecological knowledge (LEK), which can be a useful additional source of information to scientific research (Johannes *et al*., 2000). LEK may be particularly useful when monitoring/managing wildlife populations that occur in remote locations where extensive scientific studies may be impractical (Johannes, 1998; Gilchrist *et al*., 2005). This approach, known as "co-operative research", is thought to strengthen relationships and trust among resource users, scientists and managers through participation, and consequently improve the scientific data required for management and governance (Johnson and van Densen, 2007). Scientific methods and LEK often yield complementary information that can be combined to improve data quality. Nevertheless, it is important to carefully compare the outcomes of both approaches to validate their reliability (Huntington *et al*., 2004). In addition, the participatory approach can be extended into management and governance, ultimately helping to ensure, that measures taken to meet conservation and sustainability goals are successfully implemented (Coffey, 2005).

The present study assesses cetacean distribution and habitat preferences using a co-operative research approach that involved the participation of different stakeholders as well as the combination of different opportunistic sampling methods. Besides improving present knowledge of cetacean occurrence, distribution and, potentially, cetacean-fishery interactions in the study area, the aim was also to evaluate the reliability and performance of each survey method independently and combined.

2.3 MATERIALS AND METHODS

2.3.1 STUDY AREA AND LOCAL FISHERIES

The study area included the waters off Northern Spain (Basque Country, Cantabria, Asturias and Galicia) and the entire coast of mainland Portugal (43°21'N/1°47'W - 37°12'N/7°25'W).

Due to the large environmental variability within our study area in terms of coastal morphology, special marine landscapes, oceanographic conditions and marine living resources (a detailed description can be found in **Section 1.2**), the area was divided into six subregions, roughly following the zoning proposed by the ICES Working Group on Ecosystem Assessment of Western Shelf Seas (WGEAWESS; ICES, 2011a) (Table 2.1, Figure 2.1).

The Galician and Portuguese fishing fleets are mainly composed of small-scale vessels (< 12 m in length) which are usually equipped to use several types of "minor gears", such as artisanal longlines, dredges, traps and gillnets (single panel bottom-set gillnets, trammel nets, driftnets, and beach- and boat seines) to target a large variety of fish, cephalopods, crustaceans and bivalves in coastal waters. Many fishing vessels are classified as "polyvalent", i.e. change the fishing gear seasonally or use two or more gears simultaneously in the same area. Purse seiners (12 - 24 m) target shoaling pelagic species in coastal waters. In Portugal, the purse seine fishery for sardine represents around 40% of total landings. Large-scale fisheries (> 18 m) operate in areas further from the coast, targeting demersal and pelagic species with trawls, bottom-set longlines and large bottom-set gillnets. Boats based in Galician ports operate in waters all along the northern Spanish coast (Galician Ministry of Fisheries, 2013; Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2013).

2.3.2 METHODOLOGY AND DATA COLECTION

The research approach used involved active co-operation between fishers, fisheries observers, regional fisheries authorities and scientists in project management, data collection and data analysis. Opportunistic cetacean sighting data were derived from a large-scale interview survey with Galician and Portuguese fishers (mainly vessel skippers), as well as from long-term on-board observations by fisheries observers and records kept by skippers on Galician fishing vessels. The face-to-face interview survey was conducted in local fishing harbours with a structured interview questionnaire. Skippers and fisheries observers were provided with a short version of the interview questionnaire. In order to guarantee consistency in data collection, all interviewers, fisheries observers and skippers were thoroughly briefed about the appropriate procedure to fill in the questionnaires at the beginning of the respective surveys**.** In addition, a cetacean identification catalogue was provided to facilitate the correct identification of the sighted cetacean species.

Interview survey with fishers

The large-scale interview survey was primarily designed to collect data on cetacean-fishery interactions in Iberian Atlantic waters, which were analysed in more detail for Galician fisheries in **Chapter 3** of this PhD thesis (see also Goetz *et al*., 2013). For cetacean interactions with Portuguese fisheries see Vingada *et al.* (2011).

Interviews were conducted between May 2008 and August 2010. In order to cover the largest variety of fishing areas (nearshore/offshore) and target species, all important types of fisheries (see Table 2.2) were sampled in the study area, following a stratified sampling procedure. This sampling approach was selected because fishers operating the same gear were assumed to experience similar types of interactions with cetaceans (see **Chapter 3**). To get a representative sample of Galician and Portuguese fisheries we aimed for a proportional sample, i.e. the sample size (number of vessels) for each stratum being proportional to the overall composition of the sampled fleet. Many harbours in Galicia and Portugal specialize in certain fishing gears, especially the smaller harbours. Therefore, in order to get sufficient samples for each stratum, we selected harbours (the primary sampling units) according to their representativeness for a certain fishing gear (thus selecting 23 out of 128 harbours in Galicia and 27 out of 138 in Portugal) and then sampled boats (secondary sampling units) opportunistically, i.e. we targeted all fishers present and available for interviewing, within the selected harbours (Lauriano *et al*., 2009). In order to maximize the number of interviews for each sampling day, timing of interviewing was adjusted to the seasonal and daily routine of the fisheries sampled.

We designed a structured questionnaire (Appendix D) mainly composed of closed-ended questions, making sure all possible answers were covered and allowing for the answer "don't know", following White *et al*. (2005). Since we were also interested in fishers' opinions and suggestions we included some open-ended questions. In order to optimize response rates, we began with "easier", more general, questions, and asked more difficult and open-ended questions towards the end of the interview. The interviews took 15 - 20 minutes and were conducted face-to-face by two interviewers who surveyed fishers - if possible the skippers of the vessels – simultaneously, but separately, in the pre-selected harbours. Only professionally active fishers were interviewed. All interviews were kept anonymous and we assured interviewees that all personal data would be treated as confidential. Apart from information related to cetacean-fishery interactions (see **Chapter 3**), the questionnaire also included questions about cetacean sightings (species sighted and number of animals per group) and characteristics of the fishing activity (type of gear used, most important target species, catch volume and main fishing grounds, i.e. geographical location, water depth and distance to coast). A nautical map was provided to fishers and they were asked to point to the location of their usual fishing grounds. To obtain an overview of cetacean occurrence in the area that also accounts for potential seasonal variations, fishers were asked to specify cetacean species regularly or occasionally seen rather than reporting specific sightings during their last fishing trip.

When asking about cetacean sightings during the interview, we provided an identification catalogue with colour photographs taken in the area, not labelled with species names, and asked fishers to point to the species seen and indicate the name. Incorrect identification of cetaceans in the catalogue was noted by the interviewer in the questionnaire and all species-related information given in the respective interview was excluded from further analysis.

Fisheries observer records

Fisheries observers involved in our survey formed part of the Galician Fisheries Control Program (Technical Unit for Inshore Fisheries, Galician Council for Rural and Marine Affairs, Galician Government), which was initiated in 1999 to assess the status of fisheries resources and the use of the different types of fishing gears in Galician coastal waters (< 100 m water depth), as well as to implement and monitor experimental fishing programmes. The fisheries control program employs 10 observers who systematically survey the artisanal fishing fleet, covering a large variety of fishing gears, such as single panel bottom-set gillnets, trammel nets, driftnets, purse seines, hand and boat dredges, longlines and traps. In 2008, a collaboration between the Spanish Institute of Oceanography (IEO) in Vigo and the Galician Council for Rural and Marine Affairs was established with the objective to additionally record cetacean sightings as part of the observer programme. Sighting data included in our study were collected between March 2008 and July 2012.

Skipper records

Data on cetacean occurrence were registered by the skippers of 10 large-scale pair trawl vessels operating in waters off Galicia and Asturias between November 2011 and July 2012, as part of the project *Whalewatch Galicia* (10TUR009E) financed by the Galician government. The aim of the Whalewatch project was to gather information on cetacean distribution and abundance, and to evaluate the possible implementation of a whale-watching activity in collaboration with the Galician pair trawl fleet. Since the project was launched recently, information is only available for a relatively short period. The trawlers involved in the survey, usually performed fishing trips of 1 - 2 days, mainly targeting blue whiting, hake, Atlantic mackerel and horse mackerel in deep offshore waters (100 - 400 m).

2.3.3 DATA ANALYSIS

In order to simplify the dataset and to avoid digit preference, the answers given for questions concerning the main fishing grounds (geographic location, water depth and distance to coast), catches (most important target species and catch volume) and cetacean group size were grouped into categories (Table 2.1). If a respondent indicated a range of values, the midpoint value was used.

Geographic coordinates of cetacean sighting locations were registered only by fisheries observers and skippers in Northern Spain. Sighting records were entered into a geographical information system (GIS) created in ArcView 3.3 to display spatial patterns of cetacean occurrence in relation to oceanographic features and coastal morphology.

To achieve an adequate coverage of coastal and offshore areas , data were weighted based on water depth for the purpose of summary statistics to control for the different numbers of observations for shallow (< 50 m), intermediate and deep (≥ 100 m) waters. For statistical modelling, water depth is an explanatory variable and no weighting was necessary.

Generalized linear models (GLM) were used to describe the preferred habitat (geographic area, i.e. subregion, water depth, distance to coast and fisheries target species) for the most abundant cetacean species (all species representing ≥ 4% of sighting records) in the study area. GLMs are mathematical extensions of linear regression models that allow for non-linear relationships and non-normal (e.g. binomial) distribution of response variables and are therefore well suited for analysing ecological data, such as the distribution, i.e. presence-absence, of cetaceans in a certain area (Chambers and Hastie, 1992; Guisan *et al.*, 2002).

Due to the different time horizons of the three survey methods, the resulting data needed to be adjusted for modelling. While the interview survey provided information about long-term general cetacean occurrence patterns, sighting records by trawl skippers and on-board observers were derived from specific fishing trips. As a consequence, all interviewed fishers saw cetaceans regularly or occasionally during their work at sea (i.e. cetacean presence was 100%), whereas for the other two survey methods cetacean presence was only observed during some fishing trips. Cetacean absence in a certain area could therefore not be derived from the interview data. In order to analyse all three datasets jointly, only cetacean presence records were included into the model. For each species we generated pseudo-absence records using the presence records for the other cetacean species (see Barbet-Massin *et al.*, 2012).

The main target species of the fishery was used as a proxy for available cetacean prey species. Furthermore, the survey method applied was included as an explanatory variable into the model in order to assess if the different methodologies deliver similar results. Missing values for water depth were derived from a linear regression relating the variables water depth and distance to coast. Due to the collinearity between both variables, distance to coast was excluded from the subsequent analysis.

For binary response variables, i.e. presence-absence of cetaceans, a binomial distribution was used, with the logit link function if a dataset contained more ones than zeros and the cloglog link function otherwise. A GLM with all relevant covariates and interaction terms between variables was run, using a backward selection procedure. At each step, non-significant variables were dropped (F-Test) and the model was re-run, until all remaining covariates were significant. All variables included in the analysis are listed in Table 2.1. The final model was validated by verifying if the assumptions of homogeneity of variance and independence of residuals were met, also checking for the existence of influential data points (Zuur *et al.*, 2010). For categorical covariates with more than two categories dummy variables were created to investigate which categories of the covariate are significantly different from each other, and where there was a significant overall effect, a Bonferroni correction for subsequent pairwise comparisons was applied.

Statistical analysis was performed using SPSS Statistics 19 (IBM) and, for modelling, Brodgar 2.7.2 (Highland Statistics Ltd.).

Table 2.1. List of variables used for analysis with their description and categories

Variables	**Description and categories**	
Survey method	Interviews with fishers, fisheries observer records, skipper records	
Subregion (main fishing area)	Southern Bay of Biscay	(43°21'N/1°47'W – 43°48'N/7°41'W)
	North Galicia	(43°48'N/7°41'W – 42°44'N/9°05'W)
	South Galicia	(42°44'N/9°05'W – 41°54'N/8°52'W)
	North Portugal	(41°54'N/8°52'W – 39°36'N/9°24'W)
	South Portugal	(39°36'N/9°24'W – 37°01'N/9°0'W)
	Western Gulf of Cádiz	(37°01'N/9°0'W – 37°12'N/7°25'W)
Mean water depth	in metres: shallow (< 50 m), intermediate, deep (≥ 100 m)	
Mean distance to coast	in nautical miles: nearshore (< 12 nm), offshore (≥ 12 nm)	
Fishery target species	Shoaling pelagic fish Atlantic mackerel (*Scomber scombrus*), horse mackerel (*Trachurus* spp), European sardine (*Sardina pilchardus*), European anchovy (*Engraulis encrasicolus*)	
	Blue whiting (*Micromesistius poutassou*)	
	European hake (*Merluccius merluccius*)	
	Other large demersal fish pouting (*Trisopterus luscus*), common sole (*Solea solea*), turbot (*Psetta maxima*), ballan wrasse (*Labrus bergylta*), European seabass (*Dicentrarchus labrax*), white seabream (*Diplodus sargus*), blackspot seabream (*Pagellus bogaraveo*), red mullet (*Mullus surmuletus*), black scabbardfish (*Aphanopus carbo*), European conger (*Conger conger*), skates (*Raja* spp), catshark (*Scyliorhinus* spp)	
	Cephalopods common octopus (*Octopus vulgaris*), common cuttlefish (*Sepia officinalis*), European squid (*Loligo vulgaris*)	
	Shellfish (bivalves & crustaceans) scallops (Pectinidae), venus clams (Veneridae), velvet swim crab (*Necora puber*), common prawn (*Palaemon* serratus), spinous spider crab (*Maja squinado*)	
Presence-absence (individuals or groups)	Common dolphin (*Delphinus delphis*), bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), long-finned pilot whale (*Globicephala melas*), harbour porpoise (*Phocoena phocoena*)	
Cetacean group size	Small (1 - 5 animals), intermediate (6 - 25), large (26 - 50), very large (> 50 animals)	

2.4 RESULTS

A total of 1275 cetacean sighting records were collected between March 2008 and July 2012, including 73 by fisheries observers (corresponding to 2525 observed fishing trips), 48 by trawl skippers (corresponding to 604 fishing trips) and 1154 records derived from the interview survey (corresponding to 283 and 310 face-to-face interviews in Galicia and Portugal, respectively; note that individual interviews often include records for more than one cetacean species).

2.4.1 CHARACTERISTICS OF THE SAMPLED FLEET SECTION

The surveys covered trawls (20.3% of records), purse seines (17.1%), gillnets (trammel nets 11.8%, single panel bottom-set gillnets 9.1%, driftnets 1.5%), traps (11.3%), longlines (5.5%), hand and boat dredges (3.3%) and beach seines (1.6%). 18.5% of sampled boats were polyvalent. The sampled vessels operated in fishing areas from the coastline to 60 nm offshore ($\bar{x}$ = 9.2 ± 9.1 nm) in waters of 2 - 442 m depth ($\bar{x}$ = 94.4 ± 87.5 m).

In deep (≥ 100 m), offshore (≥ 12 nm) waters, trawls mainly targeted blue whiting and shoaling pelagic fish, while bottom-set longlines were used to catch large demersal fish, such as European conger, European hake and black scabbardfish.

Single panel bottom-gillnetters and polyvalent fisheries mostly targeted large demersal species in waters of intermediate depth (50-100 m). Purse seines, trammel nets and traps were mainly used in intermediate to shallow waters (< 100 m), the first to fish shoaling pelagic fish and the latter two targeting large demersal fish, cephalopods and shellfish.

In shallow waters (< 50 m) driftnets and beach seines mostly targeted shoaling pelagic fish and dredges were used to catch cephalopods and shellfish (Table 2.2).

Table 2.2. Detailed description of the sampled fleet segment covered in the survey including the main fishing grounds (expressed through mean water depth and distance to coast), main target species and the mean catch volume for each type of fishery. For each descriptor, the categories to which the majority of vessels in each fishery can be assigned are indicated by the symbol "x". Where this differs between countries, the country is indicated in parentheses (ES = Spain, P = Portugal). SPBG are single panel bottom-set gillnets.

	Type of fishing gear									
	Trawl	Longline	SPBG	Polyvalent	Purse seine	Trammel net	Trap	Driftnet	Beach seine	Dredge
mean water depth:										
shallow (< 50 m)					x	x	x (ES)	x(ES)	x (P)	x (ES)
intermediate		x	x	x (P)	x	x	x (P)			
deep (≥ 100 m)	x	x								
mean distance to coast:										
nearshore (< 12 nm)		x (ES)	x	x (P)	x	x	x	x	x (P)	x (ES)
offshore (≥ 12 nm)	x	x (P)								
main target species:										
European hake		x	x							
other large demersal fish		x	x	x (P)		x	x (P)			
blue whiting	x									
shoaling pelagic fish	x				x			x	x (P)	
cephalopods							x			x (ES)
shellfish						x (ES)	x (ES)			x (ES)
mean catch volume:										
low (< 100 kg)			x			x	x (ES)	x		x (ES)
intermediate		x	x	x (P)			x (P)	x	x (P)	
high (≥ 500 kg)	x				x					

2.4.2 CETACEAN SIGHTING FREQUENCY, SPECIES COMPOSITION AND GROUP SIZE

All interviewed fishers stated that they usually see cetaceans during fishing and navigating. Trawl skippers and on-board observers saw cetaceans infrequently (during 7.9% and 3% of fishing trips, respectively). The cetacean species most frequently sighted in the study area were common dolphin (44.2% of sightings records) and bottlenose dolphin (23.2%), the former in intermediate and large groups (6 – 50 animals), while for the latter mostly small and intermediate group sizes were observed (1 – 25). Long-finned pilot whale (9.3%) and harbour porpoise (8.5%) were also commonly sighted, mainly in small groups (≤ 5 animals), while striped dolphin (4%) mostly formed intermediate and large groups (6 – 50 animals). Small groups of baleen whales (1.8%), mainly common minke whale (*Balaenoptera acutorostrata*), as well as Risso's dolphin (1%), killer whale (*Orcinus orca*) (0.8%) and sperm whale (*Physeter macrocephalus*) (0.7%) were occasionally seen. Cetacean species could not be identified in 6.5 % of sighting records.

2.4.3 CETACEAN OCCURRENCE PATTERNS AND HABITAT PREFERENCES

Common dolphin was the dominant cetacean species in almost all subregions (except for Southern Galicia and the Western Gulf of Cádiz) (Figure 2.1), sighting probability being significantly higher in Portuguese waters than off the northern Spanish coast (Table 2.3). Common dolphins were more likely to be seen in intermediate to deep water (≥ 50 m) (Tables 2.3, 2.4) particularly over the continental shelf break (200 m), but also in coastal waters where they occurred in small groups (Figure 2.2), and more frequently when large demersal and shoaling pelagic fish were the main fisheries target species (Table 2.4).

In contrast, the presence of bottlenose dolphin was significantly higher off South Galicia, particularly within the rías (Figure 2.2), and in the Western Gulf of Cádiz (Figure 2.1; Table 2.4), sightings probability being significantly higher in shallow water (< 50 m) with no clear association to any of the main fishery target species (Tables 2.3, 2.4).

The frequency of occurrence of harbour porpoise was unrelated to water depth (Figure 2.2; Table 2.3), but significantly increased towards the south of the study area (Figure 2.2), especially if shoaling pelagic fish were the main target species of the fishery (Table 2.4).

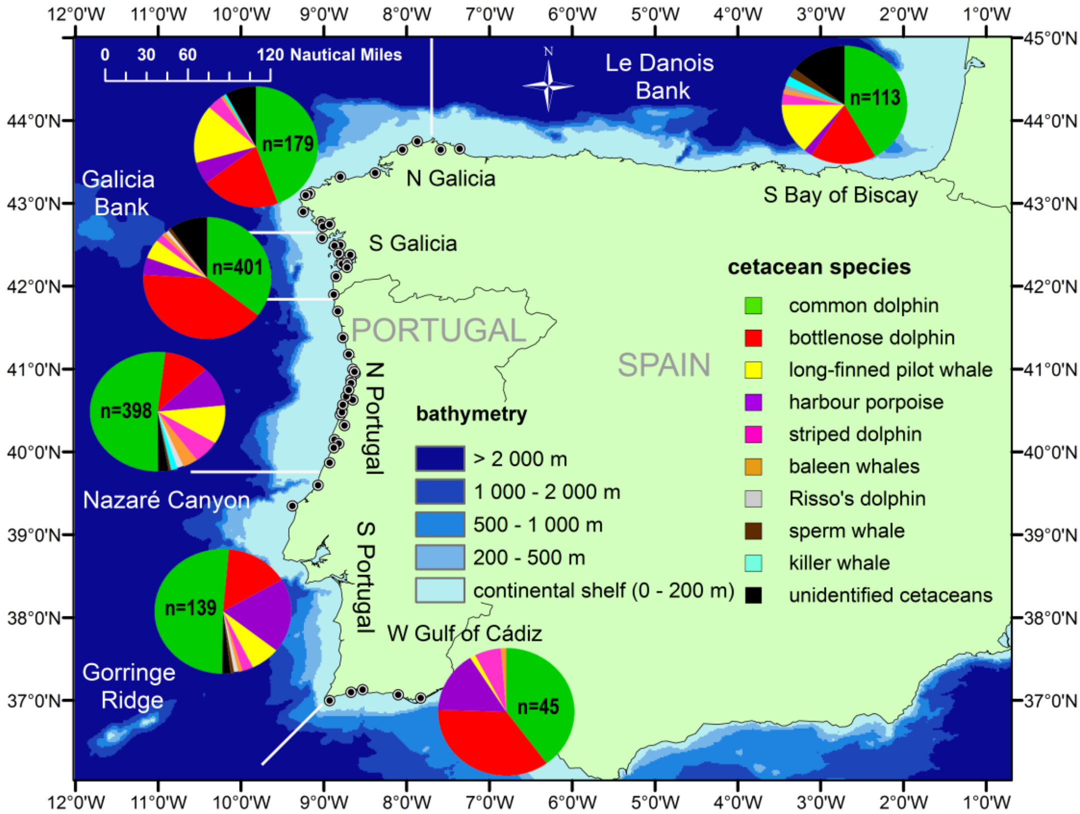

Figure 2.1. Cetacean species composition in Atlantic waters (from the coastline until 60 nm) along the Iberian Peninsula, as derived from interview data (with fishers) and on-board observations (by skippers and fisheries observers) off the North Spanish and Portuguese Atlantic coast. The species composition (proportions derived from weighted data) and the number of observations is shown for each of the six subregions. *White lines* indicate the limits between the subregions. *Black dots* indicate fishing harbours where interviews were conducted.

Long-finned pilot whales were mostly sighted in the northern part of the Iberian Peninsula (Southern Bay of Biscay, North Galicia and North Portugal) (Figures 2.1, 2.2) and more frequently when blue whiting and European hake were targeted (Table 2.4). Their frequency of occurrence was highest in deep water (≥ 100 m), over the continental shelf break (Tables 2.3, 2.4; Figure 2.2).

The likelihood of striped dolphin sightings was highest in deep waters, particularly off North Portugal and in the Western Gulf of Cádiz (Tables 2.3, 2.4; Figures 2.1, 2.2). Furthermore, the likelihood of seeing striped dolphin was highest when large demersal species were targeted (Table 2.4).

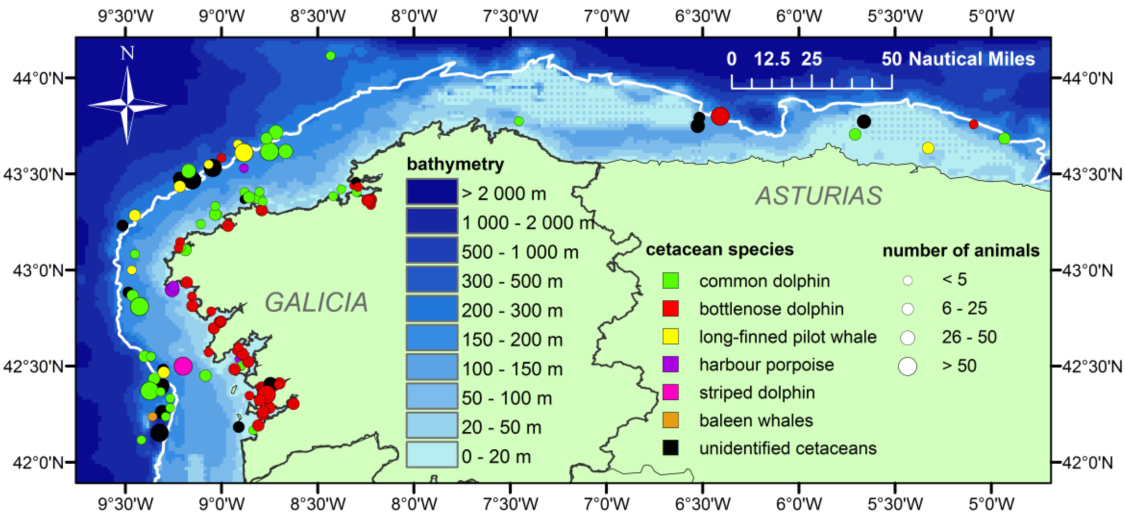

Figure 2.2. Distribution and group sizes of cetaceans off North Spain, as derived from on-board observations by fisheries observers (covering coastal waters < 100 m along the Galician coast) and by trawl skippers (operating in littoral waters of 100 – 400 m off Galicia and Asturias). The *white line* marks the continental shelf break (200 m water depth). The size of the coloured circles is proportional to the cetacean group size. Raw (unweighted) data were used to create this figure.

The few sightings of baleen whales, Risso's dolphins, killer whales and sperm whales did not allow for any clear conclusions about the geographical or bathymetrical occurrence patterns of these species, or any link with particular fishery target species (Figures 2.1, 2.2).

Table 2.3. Water depth range (metres) of cetaceans sighted in Iberian Atlantic waters. Number of observations (n) is also given.

	depth range (m)	mean ± SD	n
Common dolphin	3 – 417	98 ± 86	564
Bottlenose dolphin	2 – 417	67 ± 79	298
Harbour porpoise	3 – 267	79 ± 59	108
Long-finned pilot whale	11 – 400	168 ± 98	116
Striped dolphin	5 – 400	104 ± 91	50
Baleen whale	27 – 442	155 ± 127	23
Risso's dolphin	27 – 400	173 ± 139	12
Sperm whale	20 – 150	82 ± 39	10
Killer whale	60 – 417	174 ± 127	11

Table 2.4. GLM results (n = 786). All response variables relate to presence-absence of cetaceans and thus followed a binomial distribution. Results displayed are as follows: nominal explanatory variables included in the final model, their significance (sign) based on Chi-Square-Tests (χ^2), with p-value (the significantly different categories of each explanatory variable are specified in the text of **Section 2.4.3**), the degrees of freedom (d.f.) and the overall percentage of deviance explained (%dev) by the model. For a detailed description of variables see Table 2.1.

Response variables	Explanatory variables	χ^2	*p*-value	d.f.	%dev
common dolphin	water depth	20.31	< 0.0001	2	28.2
	survey method	22.81	< 0.0001	2	
	fishing area	105.24	< 0.0001	5	
	target species	12.75	0.0258	5	
bottlenose dolphin	water depth	23.90	< 0.0001	2	22.6
	survey method	163.9	< 0.0001	5	
	fishing area	165.39	< 0.0001	2	
harbour porpoise	fishing area	36.39	< 0.0001	5	13.9
	target species	27.06	< 0.0001	5	
long-finned pilot whale	water depth	50.79	< 0.0001	2	17.4
	survey method	20.36	< 0.0001	2	
	target species	31.55	< 0.0001	5	
striped dolphin	target species	15.58	0.0081	5	11.4
	fishing area	14.2	0.0144	5	
	water depth	7.0	0.0302	2	

2.4.4 POTENTIAL FOR CETACEAN-FISHERY INTERACTIONS

Cetacean sightings were registered by all fisheries. Common dolphins were observed in the vicinity of almost all types of fishing gears, more frequently close to vessels fishing in intermediate to deep waters with trawls, polyvalent gear and purse seines. Bottlenose dolphins, in contrast, were mostly sighted close to coastal fishing gears such as traps, driftnets, dredges and beach seines, at least in Spanish fisheries, while in Portuguese fisheries the species was also frequently seen close to longline, polyvalent and purse seine vessels. Long-finned pilot whales and striped dolphins were mainly seen near gears that are used in intermediate to deep water such as trawls, longlines and polyvalent vessels. Harbour porpoises were most frequently sighted close to set gillnets in Spanish fisheries, while in Portuguese fisheries it was most often seen by fishers operating polyvalent gear, purse seines and beach seines (Figure 2.3).

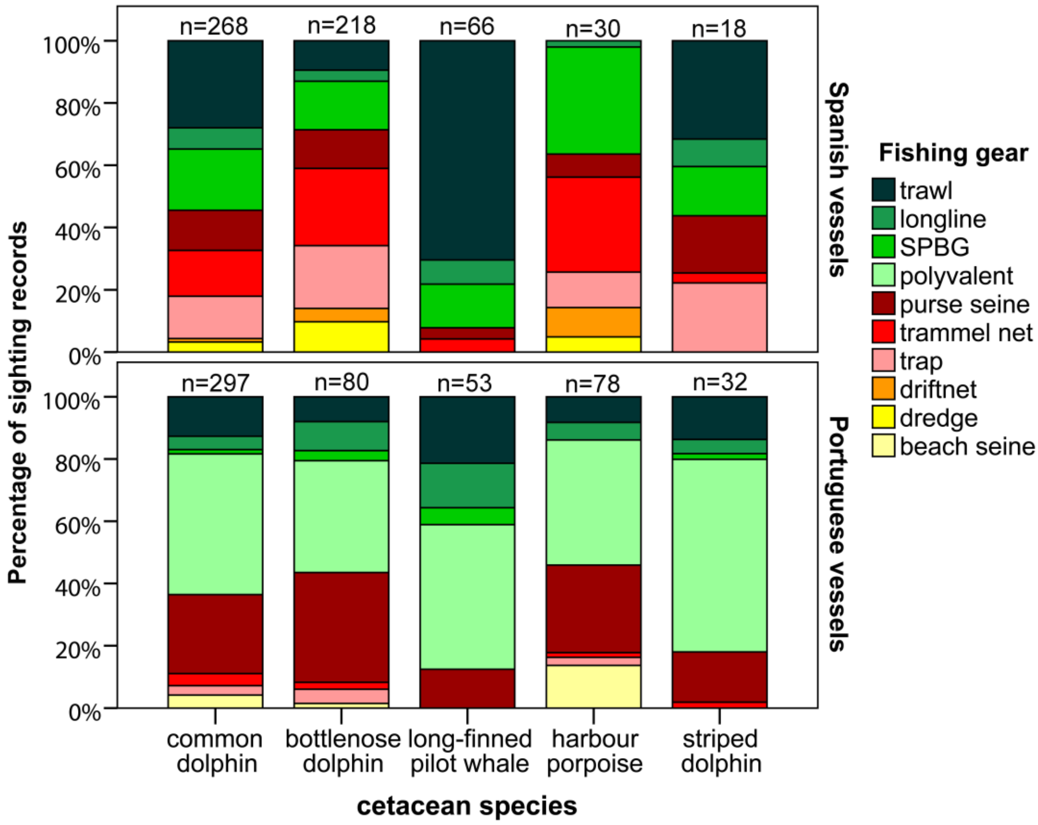

Figure 2.3. Relative percentage of sightings (weighted data) of the five most frequently sighted cetacean species by different fisheries as derived from interview data and on-board observations from Spanish and Portuguese vessels. Colouring of fishing gears indicates their main fishing depths, *green* representing deep to intermediate water, *red* intermediate to shallow water and *orange/yellow* shallow water. The number of observations (n) is given for each cetacean species. Abbreviations: SPBG – single panel bottom-set gillnet.

2.4.5 INFLUENCE OF SURVEY METHOD ON RESULTS

Survey method had a significant effect in the models for three of the main cetacean species (although since it is included as a factor in the models, we thus control for the effect of method).

Interviewed fishers reported a significantly higher sightings frequency of common dolphins than fisheries observers. Furthermore, records by trawl skippers included a significantly lower proportion of bottlenose dolphin sightings and a significantly higher proportion of long-finned pilot whale sightings compared to the other two survey methods (Table 2.3).

Harbour porpoise and striped dolphin sightings were equally likely for all survey methods.

2.5 DISCUSSION

2.5.1 CETACEAN HABITAT PREFERENCES

The cetacean species sighted, their frequency of occurrence and group sizes observed were consistent with those previously described by other authors for Iberian Atlantic waters (Aguilar, 1997; OSPAR, 2000; López *et al*., 2002, 2003, 2004; Kiszka *et al*., 2007; Wise *et al*., 2007; Brito *et al*., 2009; Pierce *et al*, 2010; ICES, 2011a; Spyrakos *et al*., 2011; Santos *et al*., 2012).

Common dolphin preferred deep shelf edge waters (≈ 200 m), but was also frequently observed in small groups in coastal waters. Their occurrence patterns, which are similar to those reported earlier by López *et al*. (2004), Kiszka *et al*. (2007), Pierce *et al*. (2010), Méndez Fernández *et al*. (2012) and Santos *et al*. (2012), are probably linked to the depth range of their principal prey which includes mesopelagic fish, such as blue whiting, which can be found over the continental shelf and slope (Robles, 1970; Whitehead *et al*., 1989), as well as more coastal species (Massé, 1996; Abaunza *et al*., 2003; Carrera and Porteiro, 2003; Santos *et al*., In Press a), such as horse mackerel, European sardine and European anchovy (Silva, 1999; Pusineri *et al*., 2007; Méndez Fernández *et al*., 2012; Santos *et al.*, 2013).

Bottlenose dolphin, in contrast, were more frequently found in shallow, coastal waters, particularly inside the rías of South Galicia and in the Western Gulf of Cádiz. This is consistent with previous findings (Aguilar, 1997; López *et al*., 2002, 2003, 2004; Pierce *et al*., 2010; Spyrakos *et al*., 2011) and confirms the hypothesis of Fernández *et al*. (2011a, b), who suggested the existence of a resident bottlenose dolphin population inside the South Galician rías that has a broader diet than animals occurring further north and in offshore waters. Bottlenose dolphin mainly feed on blue whiting and European hake, but also to a lesser extent on silvery pout (*Gadiculus argenteus),* mullet (*Mugil* spp), pouting, European conger, horse mackerel, European sardine and cephalopods (Santos *et al*., 2007; Sollmann, 2011), all of which are abundant in the shallow (< 50 m), highly productive waters inside the rías (Gabeiras Véres *et al*., 1993; OSPAR, 2000). The high dietary diversity of this dolphin species could explain why its sightings probability was not related to any particular fisheries target species in our study. Residency patterns of bottlenose dolphin have also been described for the Gulf of Cádiz (Verborgh *et al*., 2011) and for other sheltered, nutrient-rich areas such as estuaries and bays (dos Santos and Lacerda, 1987; Miller and Baltz, 2009).

As in previous surveys in Spain and Portugal, harbour porpoise was always sighted within shelf waters, mostly close to the coast, but sometimes also in deeper waters over the shelf edge, and more frequently in areas where the continental shelf is relatively narrow, such as in South Portugal (Sequeira, 1996; Kiszka *et al*., 2007; Pierce *et al*., 2010; Spyrakos *et al*., 2011; Méndez Fernández *et al*., 2012; Santos *et al*., 2012). However, we did not find a linear relationship between water depth and sightings frequency which may indicate that harbour porpoises feed over the whole continental shelf. In Galician waters their main prey species include pouting, blue whiting, horse mackerel and garfish (*Belone belone*) (Read *et al*., 2012), the first being a shallow-water species while the latter three are more abundant in deep shelf water (Wheeler, 1978; Whitehead *et al*., 1989). Similar patterns were described for the Bay of Biscay, where harbour porpoise were found to feed on both benthic coastal and offshore prey species (Spitz *et al*., 2006a).

Long-finned pilot whale and striped dolphin are considered oceanic species that prefer deep water over the continental shelf edge and slope (Perrin *et al*., 1994; Rice 1998). In our survey, long-finned pilot whales were mainly sighted off North Spain, which confirms the occurrence patterns observed for this species in earlier studies (Aguilar, 1997; López *et al*., 2004; Kiszka *et al*., 2007; Pusineri *et al*., 2007; Spyrakos *et al*., 2011), while striped dolphin was slightly more often seen off North Portugal and in the Gulf of Cádiz. Santos *et al*. (2012) observed the highest density of striped dolphins and mixed groups of common and striped dolphins off North and Central Portugal. Long-finned pilot whales and striped dolphins mainly feed on deep-water cephalopods and fish (Santos *et al*., 1996; Spitz *et al*., 2006b, 2011; Sollmann, 2011; Méndez Fernández *et al*., 2012). Our survey did not include fisheries for deep-water cephalopods, and therefore we are not able to draw any conclusion about this particular type of prey. Nevertheless, long-finned pilot whales and striped dolphins were also seen in shelf waters, most frequently when blue whiting, European hake and other large demersal fish were targeted, which supports the hypothesis that both cetacean species exploit oceanic, as well as neritic foraging areas (Kiszka *et al*., 2007; Spitz *et al*. 2011; Méndez Fernández *et al*., 2012).

2.5.2 POTENTIAL FOR CETACEAN-FISHERY INTERACTIONS

Due to their high abundance along the whole Spanish and Portuguese Atlantic coast, common dolphins have the highest probability of being involved in interactions with fishing activities in the study area. Taking regional species occurrence patterns into account, long-finned pilot whales may be more likely to interact with fisheries off North Spain, while the probability of interactions with striped dolphins is slightly higher off North/Central Portugal.

Trawl, longline and polyvalent fisheries, due to their main target species and fishing areas in intermediate to deep waters, have a high potential for conflicts with common dolphin, long-finned pilot whale and striped dolphin. Bycatch of these cetacean species in trawl nets has been previously reported by Aguilar (1997), López *et al*. (2003), Fernández Contreras *et al*. (2010) and Goetz *et al*. (2013). Coastal groups of common and striped dolphins may also interact with purse seine fisheries, where fish schools may be scattered through the presence of the dolphins, potentially reducing catch rates, as described in earlier studies by López *et al*. (2003) and Wise *et al*. (2007). Shallow-water gears, such as artisanal dredges, trammel nets, driftnets and beach seines are prone to interactions with bottlenose dolphin and harbour porpoise.

Bottlenose dolphins showed highest abundance inside the South Galician rías. Gear damage, depredation on catch and bycatch of bottlenose dolphins in set gillnets have been reported for this area by Aguilar (1997), López *et al*. (2003) and Goetz *et al*. (2013), bycatch mortality probably being high. In Portuguese waters, in contrast, bottlenose dolphins were also frequently observed close to longline, polyvalent and purse seine vessels that mostly operate in water depths over 50 m. Moreover, it is only the fifth most frequently species registered among cetacean strandings along the Portuguese coast (Ferreira, 2007; Ferreira *et al*., 2012). This may indicate that bottlenose dolphin occurrence off Portugal is less coastal than in Galician waters, which may explain the apparently lower bycatch frequency of this species in coastal gillnets in Portugal. Harbour porpoises are regularly registered among stranded animals along the North Spanish and Portuguese Atlantic coast (Covelo and Martínez, 2001; López *et al*. 2002; Ferreira, 2007; Ferreira *et al*., 2012) and when cause of death can be determined, 40 and 60% show evidence of fisheries interactions, respectively (Read *et al*., 2012). In Portugal, the species is frequently bycaught in beach seines (Silva and Sequeira, 2003; Ferreira, 2007). Cetacean interactions with traps are not likely since their design and the materials used (metal frames and wires) usually restrict the cetaceans' access to the gear.

2.5.3 EVALUATION OF THE OPPORTUNISTIC SURVEY METHODS APPLIED

The results obtained by each individual survey method were similar to each other and consistent with previous studies on the occurrence and habitat preferences of cetaceans in the same area. All three methodologies provided sightings records at low cost and reduced time expenditure when compared to logistically complex dedicated cetacean surveys. On-board observations by fisheries observers and skippers offer the possibility to identify the exact locations of cetacean presence and to assess bathymetric preferences of cetaceans in a more restricted survey area, while interview surveys have the potential to capture broad-scale distributional patterns and long-term sightings trends in a wide geographic range. Therefore, the different survey methods, apart from performing well independently, were also complementary to each other. By surveying different fisheries, coastal as well as offshore habitats could be covered, with the limitation that survey effort was restricted to fishing areas (< 450m). It is therefore possible that sighting records for deep-water cetaceans, such as striped dolphin, long-finned pilot whale, Risso's dolphin and sperm whales, are underestimated in the present study. In addition, certain bias in the sighting frequency for some cetacean species may be related to the fisheries covered by each survey method. The interview survey included small-scale and large-scale fisheries, while fisheries observers covered only small-scale fishing vessels, which mainly operate in coastal waters where the sightings probability for common dolphin is lower. Sighting records by skippers were only obtained from trawling vessels operating in offshore waters where high sightings frequency of long-finned pilot whales can be expected. Nevertheless, by pooling the different data sources together and by weighting data based on water depth, this source of error can be reduced.

Moreover, the use of pseudo-absence records, which is a widely used approach, has certain limitations (see Barbet-Massin *et al.*, 2012), the main issue being that any habitat types visited by observers but not used by any of the cetacean species will be underrepresented in the dataset.

The reliability of studies based on reports from fishers is often questioned, since personal perceptions and interests may bias the information provided (Bearzi *et al*., 2011). In addition, due to the nature of their work, fishers and fisheries observers are inevitably less effective in detecting cetaceans than dedicated marine mammal observers because observation effort is clearly restricted, and consequently reliability of absence records may be reduced (Spyrakos *et al*., 2011). Their low level of observer experience may also bear the risk of incorrect species identification.

In order to ensure a good quality of recorded data, interviews with fishers were always conducted face-to-face, because, in contrast to questionnaire surveys, personal interviewing is thought to create more confidence between interviewer and respondents (White *et al*., 2005). To avoid the possibility that interviewees chose the answer they thought the interviewer would want to hear, the respondents were always given the choice to say that they did not know the answer. Furthermore, fisheries observers and trawl skippers were thoroughly briefed about the correct observation methodology and identification of cetaceans, and they were all provided with illustrative material.

It should also be noted that the use of fisheries stakeholder data will imply a bias towards areas with fishing activity. Therefore it is difficult to determine if the cetaceans are in the area just for feeding purposes or if they use the habitat where the fisheries occur for other aspects of their life history, e.g. nursing, resting, socialising. If the project continues, it would be interesting to note the activity (e.g. feeding, travelling, etc.) of the animals as this will improve our knowledge of their habitat preferences.

Apart from these methodological constraints, the biology and behaviour of certain cetacean species may also cause certain bias in the data. Harbour porpoises, for instance, are comparatively small and shy and are therefore difficult to detect, even under calm sea conditions (Embling *et al*., 2010).

Ultimately, the greatest benefit of co-operative research involving stakeholders may be through incorporating fishers' LEK into assessment and management of cetacean-fishery interactions and through establishing trust and dialogue, that can extended into participatory management. Problems such as cetacean bycatch will not be solved by demonizing fishers; rather their active participation in seeking and implementing solutions is essential.

2.6 CONCLUSIONS

Although biological data reported and collected by fishers and fisheries observers have certain restrictions concerning their reliability, the ecological knowledge of these informants represents a valuable complement to scientific research (Gilchrist *et al*., 2005). They have long-term knowledge about abundance and occurrence of marine mammals and their prey (Johannes *et al*., 2000) and their active involvement into cetacean surveys also offers the possibility to learn about their opinions, for instance about cetacean-fishery interactions (Moore *et al*., 2010; Goetz *et al*., submitted, see **Chapter 3**). Through co-operative research, fishers' knowledge is verified and translated into scientific knowledge for use in policy-making (Johnson, 2010). Furthermore, participating in co-operative research may contribute to greater mutual understanding and trust between stakeholders and give way to the formation of partnerships between them (Hartley and Robertson, 2006). The results of this co-operative study are broadly similar to those of previous scientific surveys and we are therefore confident that both sources of knowledge can yield important information required for cetacean management and conservation, such as the identification of marine protected areas. The EU Habitats Directive aims at the establishment of a coherent European ecological network of special areas of conservation, called Natura 2000. Member States are required to identify Sites of Community Importance (SCI) which have to be designated as Special Areas of Conservation (SAC) within six years from the adoption of SCIs. This implies "*establishing priorities in the light of the importance of the sites for the maintenance or restoration, at a favourable conservation status, of a natural habitat type in Annex I or a species in Annex* II". Bottlenose dolphin and harbour porpoise are listed in Annex II and are confirmed to occur in 17 identified marine SCIs in our study area (five in Galicia, five in Asturias and eight in mainland Portugal; see **Figures 6.1, 6.2 of Chapter 6**) (ICNF, 2013; Spanish Ministry of Agriculture, Food and Environment, 2013b). The South Galician rías that are inhabited by a resident population of bottlenose dolphins are, however, only covered to a very small proportion by the list of Spanish SCIs. The area has a high potential for cetacean-fishery interactions since many commercially exploited species are also key components of the diet of cetaceans. Genetic isolation/distinction and high fisheries mortality may pose extra threats to the viability of this population and therefore the large-scale protection of its habitat should be considered in the designation of conservation areas.

CHAPTER 3

Cetacean-fishery interactions in Galicia (NW Spain)

This chapter includes work from the following publication:

Sabine Goetz, Fiona L. Read, M. Begoña Santos, Cristina Pita and Graham J. Pierce. 2013

Cetacean-fishery interactions in Galicia (NW Spain): results and management implications of a face-to-face interview survey of local fishers.

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The main author's contribution to this publication included survey and sampling design, data collection, data processing and analysis, and publication writing.

3.1 ABSTRACT

Galicia (NW Spain) is an important fishing region with a high potential for cetacean-fishery interactions. Cetacean depredation on catch and damage to fishing gear can potentially lead to substantial economic loss for fishers, while cetacean bycatch raises conservation concerns. With the aim to gather information on the types and scale of interactions and to suggest possible management strategies, we conducted face-to-face interviews with fishers in local fishing harbours, in particular to identify specific problematic interactions and to quantify the level of economic loss and bycatch rates associated with these interactions. We found that cetacean-fishery interactions are frequent, although damage to catch and fishing gear by cetaceans was mostly reported as small. Nevertheless, substantial economic loss can result from common bottlenose dolphins (*Tursiops truncatus*) damaging coastal gillnets and from short-beaked common dolphins (*Delphinus delphis*) scattering fish in purse seine fisheries. Cetacean bycatch mortality was reported to be highest for trawls and set gillnets, and probably exceeds sustainable levels for local common and bottlenose dolphin populations. Although interview data may be biased due to the perceptions of interviewees, and therefore should be interpreted with care, the methodology allowed us to cover multiple sites and fisheries within a reasonable time-frame. Minimising cetacean-fishery interactions requires the implementation of case-specific management strategies with the active participation of fishers. For set gillnet and purse seine fisheries, the use of acoustic deterrent devices (pingers) may prevent cetaceans from approaching and getting trapped in the nets. For trawl fisheries, where bycatch appears to be particularly high at night in water depths of 200-350 m, we suggest the implementation of time/area closures.

3.2 INTRODUCTION

Cetacean-fishery interactions remain a cause for concern, with cetacean bycatch being considered a serious threat to cetacean populations worldwide, particularly if threatened species are affected (IWC, 1994). In addition, damage to fishing gear and loss of catch (although the latter is difficult to prove) can potentially lead to substantial economic loss for fishers, especially in areas with acute conflict. Although interactions can be beneficial for some fisheries, for instance in purse seining where the presence of dolphins is used as a cue to detect fish concentrations (e.g. Allen, 1985), the majority of reports describe adverse effects, i.e. catch loss and gear damage through cetacean depredation (Lauriano *et al*., 2004; Gilman *et al*., 2006a; Brotons *et al*., 2008a; Gazo *et al*., 2008;

Rocklin *et al*., 2009; Bearzi *et al*., 2011; Silva *et al*., 2011) and scattering of fish (Wise *et al*., 2007). In Mediterranean waters, Bearzi *et al*. (2011) estimated the mean economic loss of artisanal trammel net fishers as € 2561 per year and Brotons *et al*. (2008a) calculated that trammel net fishers may lose around 5.3% of their total catch value due to interactions with cetaceans.

Galicia (41°48' - 43°47'N), situated in the northwest corner of the Iberian Peninsula (Figure 3.1), is the most important Spanish fishing region, accounting for almost half of the Spanish fleet and landings in 2010-2011 (Galician Institute for Statistics, 2013; Spanish Ministry of Agriculture, Food and Environment, 2013a). Cetacean-fishery interactions are frequently observed in the region, involving a large variety of gears and cetacean species (Aguilar, 1997; López *et al*., 2003; Fernández Contreras *et al*., 2010; Pierce *et al*., 2010; Fernández *et al*., 2011a,b). The short-beaked common dolphin (*Delphinus delphis*) is the most abundant and frequently sighted cetacean species in the area, followed by the common bottlenose dolphin (*Tursiops truncatus*), which mainly inhabits the coastal inlets (rías) of South Galicia. Other frequently sighted species include long-finned pilot whales (*Globicephala melas*), striped dolphins (*Stenella coeruleoalba*), harbour porpoises (*Phocoena phocoena*), Risso's dolphins (*Grampus griseus*) and other large toothed and baleen whales (López *et al*., 2002, 2004; Pierce *et al*., 2010; Spyrakos *et al*., 2011).

López *et al.* (2003) suggested that the bycatch mortality of common and bottlenose dolphins in Galician waters almost certainly substantially exceeds the maximum bycatch mortality rate (1.7% of the best available population estimate) recommended by ASCOBANS (see **Section 1.5**). Catch loss and gear damage due to interactions with cetaceans have also been reported in the area (Aguilar, 1997; López *et al*., 2003) although, to date, no detailed assessment of the extent and negative effects on fisheries has been carried out.

Cetacean conservation on the one hand and the interests of fishers on the other provide a classic example of a user-environment conflict (Proelss *et al*., 2011), that requires a holistic management approach in order to find an acceptable solution for all parties involved. The first important step for an effective management strategy is the clear identification of specific problematic interactions, i.e. fisheries and/or marine areas in which interactions are most prevalent, and the cetacean species that are most involved.

We conducted a face-to-face interview survey to collect data on the experiences and opinions of fishers. Apart from making use of fishers' ecological knowledge (FEK), the co-operation with fishers in scientific research also allows for the establishment of partnerships between scientists and fishers - which is thought to increase data quality, create buy-in among stakeholders and facilitate fishers' support for future management strategies (Johnson and van Densen, 2007).

As explained above, previous studies of cetacean-fishery interactions in Galician waters mainly focussed on the assessment of cetacean bycatch, while adverse effects on fisheries received little attention. Therefore the main objective of our interview survey was to obtain a holistic view on cetacean-fishery interactions by assessing all types of interactions ("positive" and "negative") as observed by Galician fishers, determining the types of gears and cetacean species most involved, and fishing areas (geographical location, water depth and distance to coast) where these interactions mainly occur. We further wanted to quantify the economic loss and bycatch rates associated with cetacean-fishery interactions and identify which mitigation methods were being applied by fishers. Finally, based on the results, we suggest possible management and mitigation strategies for specific cases.

3.3 MATERIALS AND METHODS

3.3.1 STUDY AREA AND LOCAL FISHERIES

Galicia's coastline (about 1200 km in length) is characterized by a series of large, coastal inlets (rías) (Fariña *et al.*, 1997) the size and orientation of which affects the frequency and intensity of the seasonal upwelling events which boost this area's productivity. The four Southern rías are much larger and oriented towards the SW, while the Northern rías are smaller and more exposed to the oceanic influence, displaying a variety of orientations (Figueiras *et al.*, 2002; ICES, 2011a). Due to these differences, which also condition the human exploitation of the rías, we have divided our study area into two subareas (North and South Galicia), Punta Queixal (5 km north of the town of Muros) representing the geographic border between the North and South Galician coasts (Fernández *et al.*, 2011a) (Figure 3.1).

There are 128 fishing harbours along the Galician coast, with Vigo, Ribeira, A Coruña, Burela and Celeiro being the most important in terms of landings (Galician Ministry of Fisheries, 2013). In 2011, the Galician fleet comprised 4734 boats of which the majority (87.6%) fishes with "minor gears" (vessel length < 12 m) such as traps, artisanal longlines and a large variety of artisanal gillnets (trammel nets, single panel bottom-set gillnets and driftnets), targeting fish, cephalopods, crustaceans and bivalves in coastal waters. A substantial proportion (26.3%) of the artisanal fleet is also engaged in shellfish harvesting (with hand- and boat dredges, rakes or manual collection). Most artisanal fishing boats are polyvalent, i.e. they shift between gears depending on the season.

Littoral, medium- to large-scale fisheries (vessel length ≥ 12 m) only account for 12.4% of the Galician fleet. These vessels target shoaling pelagic and demersal species with purse seines, bottom trawls, longlines and large bottom-set gillnets mainly in Galician waters, but also off Asturias, Cantabria, the Basque Country and outside Spanish waters (in the latter case, < 5% of the Galician fleet) (Galician Ministry of Fisheries, 2010, 2013). A detailed description of fishing gear used in Galicia fisheries can be found in Appendix A.

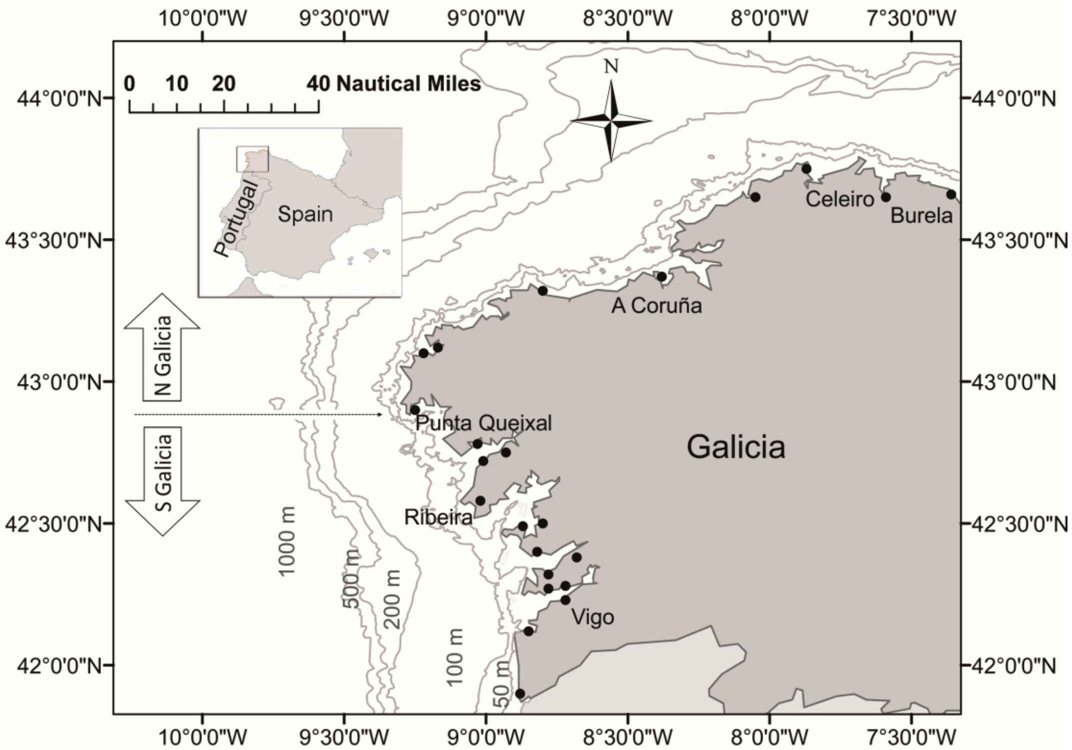

Figure 3.1. Map of the study area (Galicia, NW Spain). *Black dots* indicate harbours where interviews were conducted.

3.3.2 INTERVIEW SURVEY

Interview surveys are increasingly applied in ecology due to being an effective methodology to sample multiple sites and (in the present context) multiple types of fisheries in a comparatively time- and cost-effective way (Moore *et al*., 2010; White *et al*., 2005), that would not be possible otherwise. Furthermore, interviews offer the possibility to obtain valuable insights into the characteristics of local fisheries and their interactions with the marine environment (Johannes *et al*., 2000), including preliminary data on bycatch rates (e.g. López *et al*., 2003; Moore *et al*., 2010).

We conducted an interview survey in 23 Galician fishing harbours, applying a stratified sampling procedure, with strata based on the type of fishing gear (seven strata, see Tables 3.1, 3.2). This sampling approach was selected because fishers operating the same gear were assumed to experience similar types of interactions with cetaceans. Fisheries operating outside Spanish waters were not included in order to delimit the study area. Shellfish harvesters operating manual dredges and rakes were also excluded since interactions with cetaceans were assumed to be unlikely. Interviews were conducted face-to-face by two interviewers with a structured questionnaire. Prior to the implementation of the survey, the questionnaire was pre-tested, first conducting the interview with colleagues and then with a small number of fishers (n = 20). Unclear or ambiguous wording was corrected and sequence of questions was adjusted to improve clarity and flow. The survey collected information about: the interviewee’s profile (to determine level of experience), characterization of the fishing activity (vessel length, gears used, main fishing grounds, target species and amount of catch), attitude towards cetaceans (positive, negative, neutral), cetacean sightings (sighted species), occurrence of positive and negative interactions with cetaceans and non-cetacean species, consequences of these interactions for fisheries (description and level of damage, including catch loss through depredation and scattering of fish, gear damage and associated economic loss) and cetaceans (level of bycatch), mitigation measures employed and suggestions for solutions to avoid interactions. To obtain an overview of cetacean-fishery interactions that also accounts for potential seasonal variations, we asked fishers to describe their general experience of such interactions or, in the case of questions that included the estimation of numbers (e.g. catch loss, gear damage and cetacean bycatch), to relate their observations to the last 1 - 2 years, rather than reporting specific events during their last fishing trip. Catch loss was quantified as the % of total catch lost per depredation/scattering event.

Economic loss associated with catch loss/gear damage was quantified as the amount of money (in €) lost per year and bycatch as the number of cetaceans (by species) caught per year (Table 3.1).

At the end of each interview, we asked fishers to give us their general opinion about the factors which most influence the occurrence/level of cetacean interactions with Galician fisheries. In addition, fishers' narratives (e.g. comments and anecdotes) were recorded, when possible. This qualitative information was collected in order to complement and corroborate the results obtained by the quantitative data analysis.

For further detail on sampling procedure and the structure and contents of the interview questionnaire see **Chapter 2 (Section 2.3.2)** and Appendix D.

3.3.3 DATA ANALYSIS

In order to simplify the dataset and to avoid digit preference, the answers to some questions were grouped into categories (Table 3.1). If a respondent indicated a range of values, we used the midpoint value. To obtain comparable values for the economic loss associated with catch loss and gear damage for each fishery, we converted the reported monetary loss into the % of gross income (estimated from mean catch volume) lost per vessel/year. Boats were assigned to North or South Galicia according to the geographical location of their main fishing grounds.

To check the reliability of answers we compared the answers for the most important questions (e.g. proportion of interviewees that report negative interactions with cetaceans) collected by one interviewer with the answers collected by the other interviewer. Any significant differences might indicate that our results are biased by an interviewer effect, i.e. unintended influence of the interviewee by the interviewer. We also analysed whether the interviewees' work experience and function on-board of the vessel had a significant effect on their ability to correctly identify the cetacean species displayed in the catalogue.

Since some interviewees operated more than one type of fishing gear, we recorded multiple responses by the same interviewee for all gear–related questions (e.g. occurrence/consequences of interactions with cetaceans and other species, mitigation measures employed) and analysed these responses separately. For analysis that did not include gear type or other gear-related variables (e.g. interviewee's profile, cetacean sightings, factors influencing interactions and suggestions for solution), only one response per interviewee was included.

Since the final number of interviews per stratum (i.e. type of fishing gear) was not exactly in proportion to the relative fleets' sizes, for the purpose of summary statistics, we weighted the strata, adjusting their relative proportion in the sample to their actual proportions in the surveyed fleet (Table 3.2). For statistical modelling, gear-type is an explanatory variable and no weighting was necessary.

Generalized linear models (GLM) were used in order to determine which factors are most influential on the frequency of occurrence of cetacean-fisheries interactions, the extent of associated economic loss and the choice of mitigation methods employed (Chambers and Hastie, 1992; Cameron and Trivedi, 1998; White *et al*., 2005).

All response variables were binary and a binomial distribution was used with the logit link function if the dataset contained more ones than zeros and the cloglog link function otherwise. We ran a GLM with all relevant covariates, also including interaction terms between variables, using a backward selection procedure. At each step, non-significant variables were dropped (F-Test) and the model was re-run, until all remaining covariates were significant. All variables included in the analysis are listed in Table 3.1. The variable "harbour" was included into the model to account for any variability between harbours that was independent of gear type. We then validated the final model, checking if the assumptions of homogeneity and independence of residuals were met, also checking for the existence of influential data points. For categorical covariates with more than two categories we created dummy variables, in order to investigate which categories of the covariate are significantly different from each other, and applied a Bonferroni correction for multiple comparisons.

A rough estimation of fishery-related cetacean mortality in Galician waters was derived by extrapolating the average annual number of dead animals reported by the fisheries with highest bycatch in the current interview dataset (i.e. trawls, trammel nets and single panel bottom-set gillnets) to the entire Galician trawl and set gillnet fleets, accounting for the proportion of each fleet that reports to have bycatch.

Statistical analysis was performed using SPSS Statistics 19 (IBM) and, for modelling, Brodgar 2.7.2 (Highland Statistics Ltd.).

Table 3.1. List of variables used in the analysis with their description and categories.

	Variables	Description and categories
Interviewee profile & fishery data	harbour	names of all fishing harbours where interviews were conducted
	fisher work experience	low (< 5 years), intermediate, high (≥ 30 years)
	function on-board	skipper, crew member
	fishing gear	pair- and otter trawls[1], purse seines[1], surface driftnets[2], single panel bottom-set gillnets ("betas"[2], "volantas"[1], "rascos"[1])*, bottom-set trammel nets, i.e. three panels ("trasmallos"[2], "miños"[2])*, bottom longlines[2], traps[2]
	target species	European hake (*Merluccius merluccius*), European conger (*Conger conger*), other large demersal fish, blue whiting (*Micromesistius poutassou*), shoaling pelagic species, i.e. sardine (*Sardina pilchardus*), horse mackerel (*Trachurus* spp), Atlantic mackerel (*Scomber scombrus*), molluscs (cephalopods & bivalves), crustaceans
	type of fishery	vessel length in m: small-scale (< 12m), medium- to large-scale (≥ 12 m)
	mean catch volume	in kilogram/haul: low (< 100 kg), intermediate, high (≥ 500 kg)
	mean water depth	in m: shallow (< 50 m), intermediate, deep (≥ 100 m)
	mean distance to coast	in nautical miles (nm): nearshore (< 12 nm), offshore (≥ 12 nm)
	main fishing grounds	North Galicia (N Galicia), South Galicia (S Galicia)
Cetacean sightings & fishers' attitudes	cetacean sightings (individuals or groups)	common dolphin (*Delphinus delphis*), bottlenose dolphin (*Tursiops truncatus*), striped dolphin (*Stenella coeruleoalba*), long-finned pilot whale (*Globicephala melas*), harbour porpoise (*Phocoena phocoena*), Risso's dolphin (*Grampus griseus*), killer whale (*Orcinus orca*), sperm whale (*Physeter macrocephalus*), baleen whales
	attitude towards cetaceans	negative, neutral, positive
Interactions	positive interactions	cetaceans indicate fish schools
	negative interactions	catch damage/loss (depredation & scattering of fish) and gear damage by cetaceans and non-cetacean species, cetacean bycatch
	approach gear	cetaceans approach gear (or not)
	catch (%) loss	% of catch lost per vessel/interaction event: low (< 10%), intermediate, high (≥ 50%)
	economic (€) loss	% of gross income lost per vessel/year: minimal (<10%), significant (≥ 10%)
	bycatch	occurrence and number of animals caught per vessel/year: minimal (≤ 1), low (2-10), intermediate (11-30), high (> 30)
Mitigation	mitigation measures	change of fishing area, scare cetaceans away, wait until cetaceans leave, use of pingers, reduce fishing time, other

*different net dimension, mesh size and soak time
[1] medium- to large-scale fisheries
[2] small-scale/artisanal fisheries

3.4 RESULTS

Between May 2008 and August 2010 we conducted 283 interviews (accounting for 283 vessels) in 23 harbours along the Galician coast, covering around 6.3% of the Galician fleet operating in national waters (4450 vessels; Galician Ministry of Fisheries, 2013). If considering only the fleet of interest (excluding shellfish harvesters), interviews covered 11.6% of vessels (from a total of 3267). Including multiple responses given by the interviewees who operated more than one type of gear, the total sample size was 330 (Table 3.2). The response rate was high (97%) with only a few fishers (n = 8) refusing to take part in the survey because they had no time for the interview. There were no significant differences in answers for the most important questions between the two interviewers, suggesting that interviewer effect was negligible. The factor "harbour" was not significant in any of the GLMs, which indicates that our sampling procedure did not introduce notable bias into our data and that there were no differences between harbours not captured by other variables already included in the analysis (e.g. gear type, fishing area).

3.4.1 CHARACTERISTICS OF THE SAMPLED FLEET

Fishers interviewed were almost exclusively males (99.3%), between 19 – 65 years of age and had a mean working experience of 25 years (SD = 11.45). The majority (90.7%) reported family links to fisheries. Most interviewees were skippers (73.6%), the remainder being crew members (26.4%).

Gillnets were the fishing gear most frequently used (trammel nets 22.7%, single panel gillnets 15.8% and driftnets 3%), followed by traps (21.8%), purse seines (17.6%), trawls (otter trawl 6% and pair trawl 5.5%) and longlines (7.6%). 63.2% of our interviewees were fishing in South Galician waters, 30.3% in North Galicia and the remaining 6.5% along the Asturian, Cantabrian and Basque Country coasts. High catches (≥ 500 kg/haul) were mostly reported by trawl fishers (blue whiting, large demersal fish and shoaling pelagic species mainly in deep offshore waters) and purse seiners (shoaling pelagic species mainly in nearshore waters). Fishers operating longlines and single panel bottom-set gillnets mostly targeted hake, conger and other large demersal fish in nearshore waters and achieved low to intermediate catches (< 500 kg). Trammel nets, traps and driftnets were mostly set in shallow waters (< 50 m), achieving small catches (< 100 kg); the former two targeted cephalopods, crustaceans and large demersal fish, while the latter caught exclusively shoaling pelagic species (Table 3.2).

Table 3.2. Composition and detailed description of the surveyed fleet (excluding vessels fishing outside Spanish waters and shellfish harvesters) and sample, including the number of vessels and percentages of vessels associated with each type of fishery (stratum), and the weighting factors applied in descriptive analysis. Moreover the characteristics of each type of fishery are summarized for the sample. The % of surveyed vessel within each category is indicated. (SPBG – single panel bottom-set gillnet).

	Trawl	Purse seine	SPBG	Trammel	Driftnet	Longline	Trap	Total
surveyed fleet (N)								
number and % of vessels	84 (2.6%)	158 (4.8%)	343 (10.5%)	701 (21.5%)	148 (4.5%)	762 (23.3%)	1071 (32.8%)	**3267**
sample (n)								
number and % of interviews	38 (11.5%)	58 (17.6%)	52 (15.8%)	75 (22.7%)	10 (3.0%)	25 (7.6%)	72 (21.8%)	**330**
weighting factor	0.22	0.28	0.67	0.94	1.49	3.08	1.50	
type of fishery (vessel length):								
small-scale/artisanal (< 12 m)		6%	60%	80%	100%	60%	87%	
medium- to large-scale (≥ 12 m)	100%	94%	40%	20%		40%	13%	
mean water depth:								
shallow (< 50 m)		63%	43%	68%	92%	56%	78%	
intermediate		31%	26%	29%	8%	12%	19%	
deep (≥ 100 m)	100%	6%	31%	3%		32%	3%	
mean distance to coast:								
nearshore (< 12 nm)	11%	100%	79%	96%	100%	84%	100%	
offshore (≥ 12 nm)	89%		21%	4%		16%		
main target species:								
European hake	11%		43%	1%		23%		
European conger						48%		
other large demersal fish	22%		54%	69%	7%	29%		
blue whiting	34%							
shoaling pelagic fish	33%	100%			93%			
molluscs				17%			81%	
crustaceans			3%	13%			19%	
mean catch volume:								
low (< 100 kg)			50%	85%	59%	29%	86%	
intermediate	12%	13%	38%	12%	33%	63%	14%	
high (≥ 500 kg)	88%	87%	12%	3%	8%	8%		

3.4.2 CETACEAN SIGHTINGS: SPECIES COMPOSITION AND FISHERS' ATTITUDE TOWARDS CETACEANS

Based on weighted interview data, the cetacean species most frequently sighted were bottlenose dolphin (40.1% of sightings) and common dolphin (35.4%), followed by non-identified cetaceans (10.8%), harbour porpoise (5.2%), long-finned pilot whale (5%), and striped dolphin (1.8%). Risso's dolphin, sperm whale, killer whale and baleen whales were also occasionally sighted (all < 1%).

The majority (73.5%) of fishers were able to identify the common cetacean species correctly, independent of their work experience or their function on-board of the vessel (no significant differences were detected).

Fishers' attitudes towards cetaceans were mostly neutral (70.6%); they reported that animals do not disturb fishing operations, at least not with their gears, although they acknowledged that they may be problematic for other gears. Negative opinions about cetaceans (17.4% of respondents) were significantly related to catch- and gear damage (Table 3.3). Fishers with a positive opinion (12%) frequently replied that they like to see cetaceans, because "they break their routine" and that "their presence indicates the presence of fish schools".

3.4.3 INTERACTIONS

Based on weighted data, slightly over one-third (38.6%) of fishers reported having interactions with cetaceans, the majority (83.5%) being classified as negative.

Positive interactions were mostly associated with common dolphins, primarily because dolphins were associated with presence of schools of pelagic species in intermediate water depth (Table 3.3).

Negative interactions comprised damage/loss of catch (depredation and scattering of fish; 42.2%), gear damage (34.3%) and cetacean bycatch (23.5). In contrast, only 0.5% of fishers considered bycatch to be their most serious cetacean-related problem.

Table 3.3. GLM results: All response variables followed a binomial distribution (yes/no). Results displayed are as follows: nominal explanatory variables included in the final model, their significance based on χ^2 tests, with p-value (the significantly different categories of each explanatory variable are specified in the text of **Sections 3.4.3 and 3.4.4**), the degrees of freedom (d.f.), the number of observations (n) and the overall percentage of deviance explained (%dev) by the model. Abbreviations: Common dolphin (DDE), bottlenose dolphin (TTR), cetaceans (cet), non-cetacean species (non-cet), cephalopods (ceph) and crustaceans (crust). For a detailed description of variables see Table 3.1.

Response variables	Explanatory variables	χ^2	p	d.f.	n	%dev
negative attitude towards cetaceans	catch and gear damage by cet	104.23	< 0.0001	1	330	27.4
positive interactions	target species	33.91	< 0.0001	6	285	24.9
	water depth	9.33	0.0049	2		
	presence of DDE	3.07	0.0798	1		
cetaceans approach gear	gear damage	27.22	< 0.0001	1	313	30.2
	catch damage	7.18	0.0074	1		
cetacean catch damage	main fishing grounds	16.98	< 0.0001	1	267	31
	target species	63.39	< 0.0001	6		
catch damage by DDE	catch volume	8.85	0.0119	2	58	20.9
	water depth	6.25	0.0439	2		
catch damage by TTR	catch volume	21.45	< 0.0001	2	58	26.8
high catch (%) loss by cet	catch volume	36.62	< 0.0001	2	77	34.7
non-cetacean catch damage	catch volume	6.31	0.0426	2	232	15.6
catch damage by ceph	target species	20.13	0.0012	5	53	30.5
	water depth	12.66	0.0018	2		
catch damage by sharks	target species	12.98	0.0235	5	53	46.1
	water depth	7.22	0.027	2		
high catch (%) loss by non-cet	catch damage by crust	25.61	0.0202	1	58	22.8
cetacean gear damage	fishing gear	80.48	< 0.0001	6	229	29.3
gear damage by TTR	fishing gear	16.13	0.0028	6	66	17.7
gear damage by DDE	fishing gear	14.66	0.0119	6	89	12.4
significant economic (€) loss by cet	gear damage by TTR	4.5	0.034	1	73	5.98
non-cetacean gear damage						
gear damage by crust	fishing gear	15.09	0.0099	6	32	41.9
significant economic (€) loss by non-cet	gear damage by crust	7.99	0.0047	1	29	40.8
	gear damage by conger	4.84	0.0278	1		
cetacean bycatch (yes/no)	fishing gear	62.99	< 0.0001	6	235	30.5
	water depth	18.59	< 0.0001	2		
bycatch of DDE	fishing gear	11.41	0.0483	6	83	10.5
bycatch of TTR	type of fishery	12.04	0.0005	1	83	17.5
mitigation measures (yes/no)	gear damage	21.16	< 0.0001	1	316	46.1
	fishing gear	35	< 0.0001	6		
	catch damage	13.69	0.0002	1		

Fishers reported damage to catch and gear caused by cetaceans (52.3% of damage events), but also by other animals (47.7%), such as bony fish (conger), elasmobranchs (blue shark, *Prionace glauca*; shortfin mako, *Isurus oxyrinchus*), cephalopods (common octopus, *Octopus vulgaris*; European squid, *Loligo vulgaris*; common cuttlefish *Sepia officinalis),* crustaceans (green crab, *Carcinus maenas*; parasitic isopods *Cymothoa spp.*; lobster, *Homarus* spp), starfish and seagulls (Figure 3.2a,b).

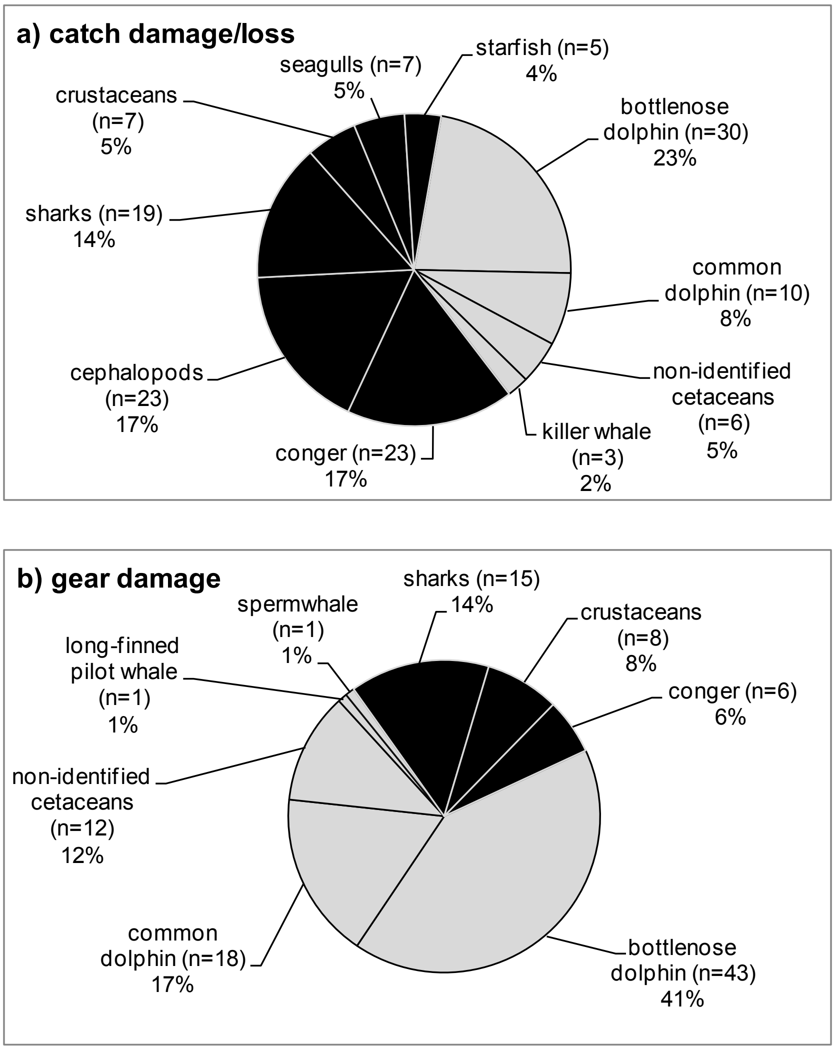

Figure 3.2. The contribution of cetacean (*grey*) and non-cetacean species (*black*) to **a)** catch damage/loss and **b)** gear damage, as reported by interviewees (in %).

Cetaceans as well as non-cetacean species were described to feed on catch or bait trapped in the gear (depredation). Fishers reported being able to identify which group was responsible for depredation, either through direct observation or based on the nature of the damage. They mentioned that cetaceans normally tear the body of the fish, leaving characteristic bite marks and often just the fish head in the nets, whereas sharks typically bite the fish in half leaving clean borders. The presence of several small bites on the fish body indicate depredation by conger, cephalopods and crustaceans. While the latter frequently bite small holes into the nets during feeding, cetaceans and sharks may tear medium-sized to large holes into the nets when they remove fish. Fishers reported that large sections of the nets may also be torn if cetaceans accidentally get entangled in static nets. In purse seine fisheries, cetaceans were frequently observed to scatter fish before the net was pursed, while in trawl fisheries they occasionally twisted the gear, resulting in catch loss.

The reported contribution of cetaceans (mainly bottlenose dolphin, followed by common dolphin) to catch damage/loss was considerably lower than the contribution of non-cetacean species (conger, cephalopods, sharks and crustaceans) (36.8% and 63.2%, respectively; Figure 3.2a), while damage to gear was reported as being more frequently caused by cetaceans than by non-cetacean species (72.1% and 27.9%, respectively; Figure 3.2b). Cetaceans were sighted close to the gear in the majority of cases when catch damage/loss (89.6% of cases) and gear damage (90%) occurred (Table 3.3). Longlines and traps were the only gears that were not affected by any type of interactions with cetaceans.

Significantly higher rates of catch damage/loss caused by cetaceans were reported by fishers operating in South Galicia and targeting shoaling pelagic species (Table 3.3).

Bottlenose dolphin was the main species associated with depredation on catch (61.4% of all reported depredation events), preying primarily on small catches, while common dolphin was reported to be most likely to scatter fish (50% of scattering events) in intermediate water depth, predominantly interfering with fisheries achieving large catches (Table 3.3).

The reported occurrence of gear damage by cetaceans was significantly higher for artisanal driftnets (100% of the driftnet users reported gear damage; n=15) than for all other gears. Single panel bottom-set gillnets also had a relatively high proportion of damage by cetaceans (54.3% of single panel bottom-set gillnet users), while there were no reports of damage to traps (Table 3.3).

Damage to gear caused by bottlenose dolphin was observed mainly in driftnets and set gillnets, while common dolphin caused net damage mostly in trawls and purse seines (Table 3.3).

Catch loss per vessel/interaction event was classified as low (<10% of total catch) by 42.6% of the fishers who had reported catch damage. 41.9% of interviewees reported high catch loss (≥50% of total catch), frequently mentioning that it is not unusual to lose the whole catch when cetaceans interfere with the fishing operation. This was significantly linked to fisheries with high catches (Table 3.3). Purse seine fishers estimated that losing the whole catch during a fishing operation is equivalent to a monetary loss of 3500 - 6000 Euros per event.

The annual economic loss associated with catch damage caused by cetaceans was, however, mostly (77.7% of catch damage reports) reported to be minimal (< 10% of gross income) (Figure 3.3). In only 22.3% of cases, economic loss was reported to be significant (≥ 10% of gross income), over half (57.1%) of these cases relating to catches of shoaling pelagic species.

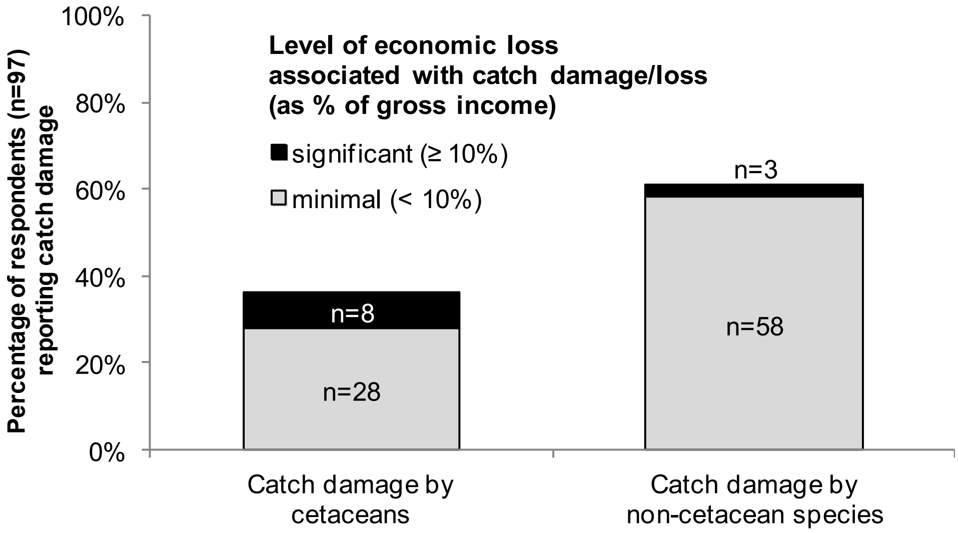

Figure 3.3. The contribution (in %) of cetaceans and non-cetacean species to catch damage/loss (a total of 97 respondents reported catch damage). The level of economic loss (as % of gross income lost per vessel/year) associated with cetacean and non-cetacean catch damage is also illustrated, *grey* referring to minimal (<10%) and *black* referring to significant (≥10%) economic loss.

Economic loss associated with gear damage by cetaceans was mainly reported to be minimal (72.9% of gear damage reports; Figure 3.4). Significant economic loss (27.1%) was strongly related to gear damage by bottlenose dolphins (Table 3.3). Although fishing gear was not significant in our model, high economic loss was a lot more common in coastal gillnets (93.8% of cases) than other gears.

Depredation by non-cetacean species was reported to be mainly associated with low catches, octopus mostly preying on catches of crustaceans in deep waters and sharks preying on hake in intermediate water depth, while gear damage was mainly associated with crustaceans damaging traps (Table 3.3).

Economic loss associated with depredation and gear damage by non-cetacean species was reported to be significant in only 4.9% (n=3) and 12.9% (n=4) of interaction events with these species, respectively (Figures 3.3, 3.4). The main non-cetacean species causing significant catch and gear damage were conger (44.4% of these cases), crustaceans (33.3%), cephalopods (21.1%) and starfish (10.5%) (Table 3.3).

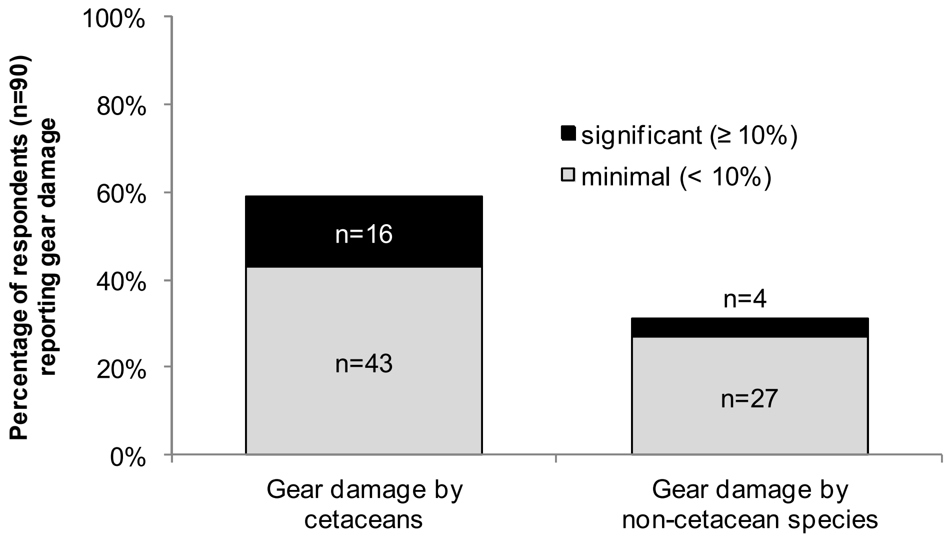

Figure 3.4. The contribution (in %) of cetaceans and non-cetacean species to gear damage (a total of 90 interviewees reported gear damage). The level of economic loss (as % of gross income lost per vessel/year) associated with cetacean and non-cetacean gear damage is also illustrated, *grey* referring to minimal (<10%) and *black* referring to significant (≥10%) economic loss.

Estimated versus perceived loss

At the end of each interview, fishers who reported suffering catch and/or gear damage by cetaceans were asked if they perceived this damage as problematic, i.e. significant for their activity, 62.5% of fishers answered "yes". This percentage markedly exceeds the proportion of interviewees whom we estimated to suffer significant economic loss.

Cetacean bycatch

One-fifth (20.2%) of fishers reported incidental bycatch of cetaceans, mainly in trawls, purse seines, trammel nets (trasmallos and miños) and single panel bottom-set gillnets (betas and volantas), identifying common dolphin as the species most frequently bycaught (53.3%), followed by non-identified cetaceans (23.3%) and bottlenose dolphin (18.3%). Long-finned pilot whale, striped dolphin and harbour porpoise represented only 5.1% of bycatch reported during interviews (based on weighted data). Almost half (49%) of the interviewees who reported cetacean bycatch, declared that they catch fewer than 10 animals per year, 44.4% had minimal bycatch (≤ 1 animal/year) and only 6.6% said that bycatch was high (> 30 animals/year). In our model, the probability of cetacean bycatch was highest for trawls, purse seines and trammel nets, and generally increased with increasing water depth (Table 3.3). Cetacean bycatch reported by trawlers (mainly of common dolphins) was concentrated in waters of 200 - 350 m depth, while for trammel nets and purse seines bycatch mainly occurred in shallower waters (< 100m). Bycatch in single panel bottom-set gillnets occurred over the whole fishing depth range (0 - 800 m) without any clear trend (Figure 3.5). Bycatch of bottlenose dolphins was significantly related to artisanal boats (Table 3.3). According to fishers, animals encircled in purse seines usually survived, either by escaping unaided or being helped to escape by the lowering of the corkline.

Of those fishers reporting any bycatch, trawl fishers reported catching 12 animals per year on average, and fishers operating fixed gillnets reported catching two (trasmallos and volantas) or three (miños and betas) animals per year on average. Extrapolating these average numbers to the entire Galician trawl and set gillnet fleets, accounting for the proportion of each fleet that reports to have bycatch (68.4% of 84 trawls, 30% of 363 trasmallos, 54.5% of 39 volantas, 52.4% of 338 miños and 25% of 301 betas), this would give a total estimate of 1707 cetaceans killed by Galician fisheries each year (159 common dolphins, 136 bottlenose dolphins, 73 long-finned pilot whales, 40 harbour porpoises and 1299 non-identified cetaceans).

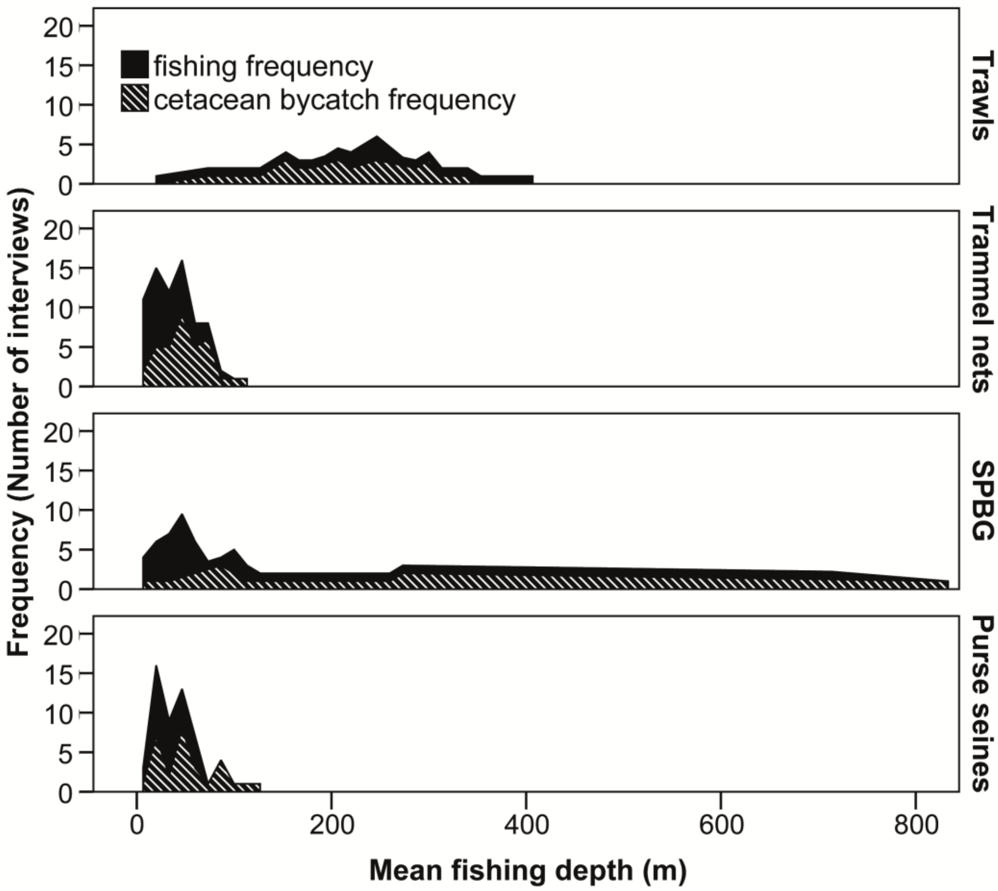

Figure 3.5. Reported depth distribution (mean fishing depth in m) of fishing activity (*highlighted in black*) and occurrence of cetacean bycatch (*area with diagonal stripes*) for trawls, set gillnets (trammel nets and single panel bottom-set gillnets - SPBG) and purse seines.

3.4.4 MITIGATION MEASURES

Almost half (42.6%; weighted percentage) of the interviewees who reported negative interactions also reported the application of mitigation. The main measure was to navigate to alternative fishing grounds away from the cetaceans (44.4% of fishers that used mitigation measures). Another strategy was scaring the cetaceans away from the vessel (28.8%), for instance by making noise, using firecrackers, throwing stones at the animals or hosing them with seawater. Some fishers mentioned that they postpone the fishing operation until the cetaceans leave the area (16.4%) and very few interviewees reported that they reduce the fishing/soak time (7.1%) or use pingers (3.3%) to avoid interactions.

Mitigation measures were used significantly more frequently by fishers suffering gear and catch damage, compared to those suffering no damage, particularly by those using driftnets and purse seines (Table 3.3), and when scattering of fish was reported as the main problem.

3.4.5 INFLUENTIAL FACTORS AND FISHERS' SUGGESTIONS FOR SOLUTIONS

When asking fishers about the most important factors influencing the amount of interactions with cetaceans, they indicated that the type of fishing gear used was the most influential factor (56.6%). Gillnets were identified as the most problematic gear. Another factor frequently indicated was the catch target species (22%), namely when fishing for shoaling pelagic species. 8.1% of interviewees believed that season was also an important factor, with interactions occurring more frequently in summer and spring and 6.8% mentioned that fishing area may be influential, interactions occurring more frequently nearshore than offshore. Other factors mentioned (< 5 %, in each case) included fishing time/duration, weather, water depth, cetacean behaviour, moon cycle and resource availability.

Relatively few fishers (15.7%) provided suggestions about how to solve the problem of cetacean-fisheries interactions. Suggestions included measures to benefit fisheries and cetaceans in approximately equal proportions. The former ranged from deterring cetaceans from approaching the gear (for instance with acoustic deterrent devices) and financial compensation, to a few rather extreme suggestions, namely the hunting and deliberate killing of cetaceans reduce the local population.

Measures to benefit cetaceans mainly comprised the prohibition of fishing gears with high bycatch levels, a large-scale reduction of fishing effort and the establishment of cetacean conservation areas, where fishing is restricted. The need for alternative "cetacean-friendly" fishing methods and more environmental education was also emphasized.

3.5 DISCUSSION

3.5.1 CETACEAN SPECIES SIGHTED AND THEIR INTERACTIONS WITH FISHERIES

Quantitative analysis as well as qualitative information provided by Galician fishers suggests that the occurrence/level of cetaceans' interactions is primarily influenced by the type of fishing gear, target species and fishing area. Coastal demersal gillnet fisheries and purse seine fisheries for shoaling pelagic species are the main fisheries affected by catch/gear damage, while offshore trawling causes the highest cetacean bycatch mortality.

The cetacean species sighted by the respondents and their relative frequency of occurrence are consistent with those previously described by other authors for the North West Iberian Peninsula using a variety of methods, including sightings from vessels and from the coast, and interviews (Aguilar, 1997; López *et al*., 2002, 2003, 2004; Pierce *et al*., 2010; Spyrakos *et al*., 2011).

As in several similar studies, bottlenose dolphin was reported to be the species most strongly associated with depredation and gear damage, particularly for set gillnets (Aguilar, 1997; Lauriano *et al*., 2004; López *et al*., 2004; Brotons *et al*., 2008a; 2009; Rocklin *et al*., 2009; Bearzi *et al*., 2011). Common dolphins were also frequently mentioned to interact with the fishing activity, but primarily with purse seines. Although the report of interaction frequency was generally high in our survey, the majority of interviewees had a neutral or positive attitude towards cetaceans and the economic loss resulting from negative interactions was mainly classified as low. This contrasts with the perception of fishers affected by catch loss and gear damage who mostly classified cetacean-fishery interactions as "problematic". This discrepancy between the estimated and the perceived impact of cetacean-fishery interactions, which was also observed by Wise *et al*. (2007) and Silva *et al*. (2011) may be linked to the fact that fishers who frequently experience negative interactions with cetaceans might tend to exaggerate the real economic impact in order to draw attention to their situation or may perceive the interviews as an opportunity to influence decision-making with respect to governmental monetary compensations for catch loss and gear damage (Bearzi *et al*., 2011). In contrast, cetacean bycatch that was reported by almost one-quarter of fishers, was rarely considered a serious problem, most likely because (apart from occasional gear damage) bycatch did not have a direct negative impact on fishers' profit and/or because fishers may be afraid of the implementation of bycatch reduction measures that restrict their activity.

However, there were two circumstances where dolphins were reported to have a significant negative impact on fisheries: interactions between purse seiners and common dolphins and interactions between bottlenose dolphins and coastal gillnets. Purse seine fisheries target sardine, one of the main prey species of common dolphins in Galician waters (Méndez Fernández *et al*., 2012; Santos *et al*., 2013). They frequently use observations of dolphins as a cue for the presence of a large fish school, although, in contrast, some interviewees indicated that if dolphins are in an area, they avoid it. Fishers reported that dolphins cause scattering or sinking of entire fish schools, frequently leading to the complete loss of the catch for the affected haul. Such occurrences are plausible and are probably directly linked to the fish school's awareness of the presence of a predator (Wise *et al*., 2007). Nevertheless, due to the low frequency of interactions and stable catch rates, Wise *et al*. (2007) concluded that small cetaceans are not harmful to purse seine fisheries in Portuguese waters. Our study, however, indicates that catch may be significantly reduced if cetaceans interact during purse seining. In fishing areas with high dolphin abundance such interactions are likely to occur and associated economic losses may therefore be substantial.

Gear damage by bottlenose dolphins in particular was considered to be a problem for fishers who target shoaling pelagic species with artisanal surface driftnets, and hake and other large demersal fish with single panel bottom-gillnets inside the South Galician rías. Both types of fish are important in the diet of bottlenose dolphins (Santos *et al*., 2007). As the dolphins attempt to remove fish trapped in the nets, they frequently tear large holes in the net (Brotons *et al*., 2008a). Fishers also indicated that dolphins sometimes get entangled in the gear and damage larger sections of the net. Fishers mentioned that net repair is too expensive and that they usually continue using the damaged gear (which becomes ineffective, reducing catch) until the end of the fishing season before replacing it.

In contrast, fishers reported that depredation on catch by bottlenose dolphins occurred less frequently than gear damage by the same species in set net fisheries. This may indicate that dolphins mainly prey on fish in the water column and only occasionally take fish from nets as an additional food source, which was also hypothesized by Rocklin *et al*. (2009).

It was not only cetaceans that were reported to interact with fisheries: damage of catch by crustaceans, cephalopods, conger and sharks was more frequently reported than damage by dolphins in coastal artisanal net fisheries. Cephalopods were mentioned to consume all the shellfish from gillnets and traps and leave only the shells, while crustaceans and conger were reported to cause significant monetary loss (although only occasionally). It is therefore important to note that non-cetacean predators can also contribute substantially to catch loss and gear damage (Rocklin *et al*., 2009; Bearzi *et al*., 2011). The types of catch and gear damage described by our interviewees were consistent with those reported by similar studies (Secchi and Vaske, 1998; Brotons *et al*., 2008a; Gazo *et al*. 2008; Gönener and Özdemir, 2012) and we are therefore confident that fishers were able to identify types of damage correctly. However, it is possible that, since dolphins were more visible to fishers than other predatory species, some damage to catch and gear attributed to dolphins may be caused by other species. Seasonal or spatial variation in fish abundance or catchability, as well as oceanographic conditions, may be also responsible for reduced catches (Lauriano *et al*., 2004). Gear damage may also arise when the nets get caught on the seafloor or collect marine debris, as mentioned by some interviewees.

Galician fishers also reported occurrence of cetacean bycatch, which was classified as particularly high for trawls, purse seines and trammel nets, mainly affecting common dolphins. This is consistent with the findings of Aguilar (1997), López *et al*. (2003) and Fernández Contreras *et al*. (2010) for the same area. The high bycatch frequency of common dolphins in trawl nets is probably linked to the fact that pair trawlers off Galicia usually operate in water depths of 125 - 700 m, mainly targeting blue whiting, horse mackerel, Atlantic mackerel and hake (Fernández Contreras *et al*., 2010), which overlaps with both important prey species of common dolphins and the range of water depths over which the species occur (López *et al*., 2004; Pierce *et al*., 2010; Santos et al., 2013; see also **Chapter 2**). Purse seines can be considered to have a low impact on cetacean mortality due to the high survival rate of encircled dolphins (Aguilar, 1997; Wise *et al*., 2007; Hamer *et al*., 2008).

In contrast, bottlenose dolphins and harbour porpoises, due to their generally more coastal distribution in Galician waters (López *et al*., 2004; Pierce *et al*., 2010), are more likely to interact with set gillnets. Nevertheless, the reported bycatch rate of these species was relatively low when compared to common dolphins in trawls. Cox *et al*. (2003) and Buscaino *et al*. (2009) both pointed out that bottlenose dolphins frequently interact with gillnets, but rarely get entangled.

Although the bycatch rates reported by Galician fishers may seem to be moderate (mostly < 10 animals per year), it has to be considered that coastal gillnet fisheries make up a large proportion of the Galician fleet and that the sum of animals killed by this fishery may actually be considerable. Our preliminary estimate of fishery-related cetacean mortality for trawls and set gillnets is 1707 animals per year (of which 159 are common and 136 bottlenose dolphins); see Read *et al*., In Prep, for a more detailed examination of likely bycatch rates based on the interview data. This total estimate is almost double that derived by López *et al*. (2003), who estimated that 917 cetaceans (trawls and gillnets being responsible for 90.3% of bycatch, i.e. 828 cetaceans) are killed by fisheries in Galician waters each year (including approximately 690 common and 48 bottlenose dolphins in trawls and gillnets only), based on interview data from the late 1990s. It is however difficult to compare the two sets of figures due to the much higher proportion of non-identified cetaceans in the present dataset. In addition, survey designs, including detailed content of the questionnaires, were different.

Based on results from the SCANS II survey (SCANS II, 2008), Santos *et al.* (accepted) estimated that the common dolphin population in Galicia and adjacent Northern Spanish waters was around 7050, which compares to an estimate of 8140 for Galicia, from opportunistic surveys, used by López *et al.* (2003). Similarly, using SCANS II results, the bottlenose dolphin population of the North West Iberian Peninsula, excluding animals in the coastal rías, is probably around 3000; López *et al.* (2003) quoted a figure of 660 animals for Galician waters including the rías. Even selecting the smallest bycatch estimates and the largest population size estimates from these given above, the annual bycatch rates for common dolphin (159/8140 or 2.0%) and bottlenose dolphin (48/3000 or 1.6%) are close to the limit of 1.7% recommended by ASCOBANS, and other combinations of these figures would yield annual bycatch rates of over 10% for common dolphins and over 20% for bottlenose dolphins. Moreover, analysis of stranded animals in Galicia suggests that fishery-related mortality rates of harbour porpoise may be unsustainable (Read *et al*., 2012).

Based on the present study, there is cause for concern in the case of both common and bottlenose dolphins. Given the limitations of interviews as a means to collect reliable quantitative data, we believe that a new study of cetacean bycatch in Galicia, based on on-board observation, is urgently needed.

3.5.2 MITIGATION MEASURES AND POSSIBLE MANAGEMENT STRATEGIES

Interviewees frequently mentioned that "interactions are natural and we have to accept them" and the majority offered no suggestions about solutions. Nevertheless, a number of fishers provided constructive, feasible ideas.

Avoidance of fishing areas where dolphins are present was the most frequently mentioned strategy for all types of fisheries. However, due to the substantial overlap between cetacean feeding areas and preferred fishing grounds, the avoidance strategy obviously has its limitations. Technical solutions, such as acoustic deterrent devices, were mentioned by a few affected fishers.

In our study we were able to identify three specific problematic cetacean-fishery interactions, each of which is likely to need a case-specific management strategy. For set gillnets, which are mostly used inside the South Galician rías, the goals are to reduce bycatch of bottlenose dolphins as well as damage to gear, while in purse seine fisheries common dolphins need to be deterred from approaching the nets in order to avoid scattering of fish. The use of pingers, which are low-intensity acoustic signal generators emitting mid to high frequency sounds, designed to prevent small cetaceans from approaching fishing gear (Reeves *et al*., 2001), represent a possible solution, at least for static gears. The devices can be relatively easily attached to nets, although operational issues have been reported, including pinger breakages and interference with fishing operations (e.g. Northridge, 2011; Dawson *et al.*, 2013). Numerous trials showed that pingers can be effective in reducing damage caused by, and bycatch rates of, bottlenose dolphins (e.g. Leeney *et al*., 2007; Brotons *et al*., 2008b; Gazo *et al*., 2008; Buscaino *et al*., 2009; Read and Waples, 2010; Gönener and Özdemir, 2012) and common dolphins (Barlow and Cameron, 2003; Carretta and Barlow, 2011), although there are also studies that could not demonstrate any obvious aversive reactions of common dolphins to pinger sounds (e.g. Sagarminaga *et al*., 2006; Berrow *et al*., 2008). McPherson *et al.*, (2004) reported that pingers are not effective in reducing bottlenose dolphin entanglement in gillnets and that the dolphins sometimes behaved aggressively toward pingers, repeatedly attacking them. All of the above-mentioned trials were based on fixed gears. For mobile gears like trawls, the high level of associated noise means that pingers are unlikely to be effective: additional noise is unlikely to enhance detection of the gear (thus permitting avoidance) or act as a deterrent. Operation of a purse seine is perhaps not as noisy as trawling but in addition to the main vessel, motor launches may be deployed to help herd the fish into the net (e.g. ICCAT, 2008) so pingers may not be effective.

Even in the case of static gear, the long-term effectiveness of pingers is still controversial since especially bottlenose dolphins may potentially habituate to the pinger sounds and consequently start to ignore them or even become attracted to them (e.g. Cox *et al*., 2003; Northridge *et al.*, 2003b). For common dolphins, however, no such effect was detected by Carretta and Barlow (2011), who conducted a long-term study over 19 years. The likelihood of habituation may be minimized by using responsive pingers that only activate when receiving cetacean clicks (Leeney *et al*., 2007) or by periodically modifying pinger emission frequencies (Gazo *et al*., 2008). Furthermore it is essential to ensure that the signal does not affect the fishery target species in order to avoid negative impacts on catch rates (see **Chapter 4**). Since pingers are relatively expensive and may not be affordable for small-scale fishers, governmental subsidies for the acquisition of pingers could be needed.

The possibility of avoiding fishing grounds with high cetacean abundance should be explored. Although it may not be viable if dolphins favour the areas with highest fish abundance, there may be differences between species and size classes targeted by fisheries and those preferred by dolphins which would permit some spatial separation.

For trawl fisheries, the mitigation of dolphin bycatch is the main objective. There are certain operational factors that can influence bycatch: incidental capture is more likely to occur in shallow waters (< 300m) and during nocturnal fishing (Morizur *et al*., 1999; López *et al*., 2003; Fernández Contreras *et al*., 2010). Interviewees reported that most dolphins were captured in water depths between 200 and 350m. Time/area closures can be effective when patterns of bycatch are predictable in time and space (Murray *et al*., 2000), and therefore a ban on trawling in waters shallower than 250m, as suggested by Fernández Contreras *et al*. (2010), and a reduction of nocturnal trawling (López *et al*., 2003) could dramatically reduce cetacean bycatch in Galicia.

3.5.3 THE SUITABILITY OF INTERVIEW SURVEYS TO ASSESS CETACEAN-FISHERY INTERACTIONS

Our qualitative research results are in accordance with quantitative findings for the area (Aguilar, 1997; López *et al*., 2002, 2003, 2004; Fernández Contreras *et al*. 2010; Pierce *et al*., 2010; Spyrakos *et al*., 2011), showing that fishers' ecological knowledge can serve as a useful data source that may also be valuable for wildlife management (Johannes *et al*., 2000). Nevertheless, information based on reports from fishers (like all interview data) may be potentially influenced by the opinions, perceptions and personal interests of the interviewees (Bearzi *et al*., 2011). Therefore the damage and bycatch rates indicated by our interviewees should be interpreted with care as economic loss may be overestimated, while bycatch rates are likely to be underreported by fishers.

Nevertheless, interview surveys can be particularly useful where extensive scientific studies may be impractical or financially unfeasible (Johannes, 1998), as it is the case for cetacean-fishery interactions that usually occur in remote locations over a wide geographic area. Interview surveys are clearly less costly and time-consuming than on-board sampling and allow for a wide geographic coverage and sampling of multiple gears at the same time (White *et al*., 2005). In our study we covered more than 5% of the fishing fleet of interest, which is in accordance with the minimum sample size recommended for interview surveys by Czaja and Blair (2005). Furthermore, by applying a stratified sampling strategy (White *et al*., 2005; Moore *et al*., 2010), we ensured the sample was reasonably representative of the entire Galician fleet, covering all types of fisheries operating in coastal and offshore waters that are possibly affected by interactions with cetaceans.

The assessment of cetacean-fishery interactions only by on-board observers would be financially and logistically unfeasible. Based on a fleet size of 3267 vessels fishing five days a week, around 42 610 observer days, would be needed every year to monitor 5% of the fleet activity, i.e. requiring 163 full-time observers. Clearly, this is a maximum estimate (some vessels probably fish fewer days per week or only during certain seasons) and observations could be focused on those fishing activities most likely to generate interactions with cetaceans. López *et al.* (2003) estimated that a minimum of between 500 and 2000 observer trips per year would be needed to quantify cetacean bycatch in Galician fisheries. Nevertheless, the need for additional data sources is apparent. For routine monitoring, some combination of vessel-based observations by trained observers in a small fraction of the fleet, interview surveys and (as recently trialled in several studies, see ICES, 2011b) on-board video cameras may provide the best solution.

We chose face-to-face interviews because, in contrast to telephone or postal surveys, they create more confidence between interviewer and respondents, allowing for good quality of recorded responses, a high response rate and, consequently low non-response bias (i.e. difference in the answers of respondents from the potential answers of those who did not answer) (Lien *et al*., 1994; Czaja and Blair, 2005; White *et al*., 2005). A common point of criticism of this methodology is the interviewer effect, i.e. the unintended influence on the interviewee through the interviewer (Czaja and Blair, 2005). In our survey we did not detect such an effect.

3.6 CONCLUSIONS

The data derived from our interview survey indicate that cetacean-fishery interactions are frequent in Galicia, although negative consequences for fishers and cetacean bycatch levels were mostly classified by fishers as low to moderate. Nevertheless some interactions may lead to serious conservation and/or economic problems. Our preliminary calculations suggest that bycatch rates for both common dolphin and bottlenose dolphin are likely to be unsustainable. It is therefore essential to improve the situation of affected fisheries and cetacean populations through the implementation of appropriate management plans, the success of which largely depends on fishers' willingness to cooperate, apart from legal enforcement and monitoring (Campbell and Cornwell, 2008). There are many cases where cetacean bycatch levels have been successfully reduced with the direct co-operation of fishers (IWC, 1994). Fishers have expertise with fishing gears and should therefore be involved in the creation and trial of new gear technologies. Their active participation into dolphin watching activities, as well as the promotion of eco-labelling of fish and fishery products could even help to improve earnings (e.g. Salomon *et al*., 2011). If the large-scale use of pingers is considered as a management option, long-term scientific trials need to be conducted to determine which type of pinger is most effective and least likely to cause habituation in dolphins. It could also prove useful to put cameras on nets to verify the cetacean species that cause damage to gear, at what point during fishing activities bycatch occurs, and how many fish are actually removed or damaged, in order to direct research and mitigation measures on a more species- and gear-specific basis.

CHAPTER 4

Effect of acoustic deterrent devices on two commercially important pelagic fish species in Iberian Atlantic waters

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Sabine Goetz, Begoña Santos, José Vingada, Damián Costas Costas, Antonio González Villanueva and Graham Pierce. The effect of acoustic deterrent devices "pingers" on two commercially important shoaling pelagic fish species in Iberian Atlantic waters

The main author's contribution to this publication included survey and sampling design, preparatory work for the laboratory experiments (arrangement of capture and transport of live fish, preparation of materials), data collection (behavioural observations and blood cortisol sampling), data processing and analysis, and publication writing.

4.1 ABSTRACT

Acoustic deterrent devices (pingers) that are designed to deter marine mammals from fishing gear have been successfully employed to reduce cetacean-fishery interactions. In Spanish and Portuguese fisheries they may be applied to mitigate catch loss, gear damage and incidental cetacean bycatch resulting from interactions between net fisheries and locally abundant cetacean species, such as short-beaked common dolphin and common bottlenose dolphin. Pinger use in affected fisheries is, however, only feasible if negative effects of the pinger sound on the fisheries target species can be ruled out. Noise can induce short-term stress responses in fish that are reflected in increased blood cortisol concentrations and by alterations of their swimming/schooling behaviour, which may potentially lead to reduced catch rates. In order to test this hypothesis, the aim of the present study was to analyse the behavioural (changes in swimming behaviour) and physiological (differences in blood cortisol concentration) stress response of two shoaling pelagic fish species, European sardine (*Sardina pilchardus*) and Atlantic horse mackerel (*Trachurus trachurus*), both important target species of net fisheries in Iberian Atlantic waters, to the sounds of three commercially available pinger models with different technical specifications. The response of wild captive fish to the pinger sounds were tested in tank experiments, analysing their swimming behaviour by means of underwater camera images and additionally assessing the physiological stress level of fish by measuring their blood plasma cortisol concentration. Mixed effect models were used for statistical analysis. We found that the sounds of two of the three pinger models tested caused subtle changes in the swimming behaviour of both fish species and in sardine plasma cortisol concentrations. Although the slight behavioural and physiological alterations were statistically significant, they were very small when compared to the values reported in similar studies. We therefore believe that the variation measured in our study is more likely to be caused by biological and environmental factors rather than reflecting an acute stress response. Our results indicate that the sounds of the trialled pinger models do not have a negative effect on the swimming behaviour of sardines and horse mackerels and should consequently not have any significant impact on catch rates. As a next step, we recommend to test the pingers in long-term field experiments in the study area with the active co-operation of affected fisheries, to assess pinger efficiency on target cetaceans, the magnitude of possible side effects on non-target cetaceans, catch rates of fisheries target species, as well as the willingness of local fishers to accept this mitigation tool.

4.2 INTRODUCTION

Pingers are acoustic deterrent devices (ADDs) that are designed to deter cetaceans from fishing gear by emitting "unpleasant" high-frequency sounds in the hearing range of the animals (Reeves *et al*., 1996). They are primarily employed as a bycatch reduction measure (Kraus *et al*., 1997; Trippel *et al*., 1999; Carlström *et al*., 2009; Gönener and Bilgin, 2009), but can also be effective in reducing cetacean depredation on catch (Brotons *et al*., 2008b; Gazo *et al*., 2008; Buscaino *et al*., 2009).

In waters off Galicia (NW Spain) and Portugal mainland, interactions with cetaceans are particularly problematic for purse seine, trawl and coastal gillnet fisheries (López *et al*., 2003; Vingada *et al*., 2011; Goetz *et al*., 2013, see **Chapter 3**). The presence of short-beaked common dolphins (*Delphinus delphis*) during purse seining operations may cause the scattering of fish schools and consequently catch loss, while common bottlenose dolphin (*Tursiops truncatus*) depredation on artisanal bottom-set gillnets and driftnets may result in damaged fishing gear. Associated economic loss may be substantial. Cetacean bycatch is mainly an issue in trawl and set gillnet fisheries, primarily affecting common dolphin, bottlenose dolphin and harbour porpoise (*Phocoena phocoena*) (Aguilar 1997; López *et al*., 2003; Goetz *et al*., 2013). Bycatch rates of these species are likely to be unsustainable in Iberian Atlantic waters (López *et al*., 2003; Read *et* al., 2012). Pingers have successfully been employed to discourage common dolphin (Barlow and Cameron, 2003; Carretta and Barlow, 2011) and bottlenose dolphin (Leeney *et al*., 2007; Brotons *et al*., 2008b; Gazo *et al*., 2008; Buscaino *et al*., 2009; Read and Waples, 2010; Gönener and Özdemir, 2012) from approaching fishing gear in previous studies and may therefore be an efficient tool to mitigate cetacean-fishery interactions in the affected net fisheries. However, if the large-scale use of pingers is considered as a potential management scenario, it is essential to rule out any negative effects of the devices on catch performance to ensure their acceptance by fishers (Gazo *et al*., 2008).

There have been a few studies in the past to assess the effect of acoustic alarms on fisheries target species and, although in most cases no significant effect on catch rates was detected (Kraus *et al*., 1997; Trippel *et al*., 1999; Culik *et al*., 2001; Cox *et al*., 2003, Buscaino *et al*., 2009; Gönener and Özdemir, 2012), there are some species such as European seabass (*Dicentrarchus labrax*), Atlantic herring (*Clupea harengus*) and thicklip grey mullet (*Chelon labrosus*), that showed aversive behaviour while being exposed to the pinger sounds in experimental tank trials (Kastelein *et al*., 2007). Kraus *et al*. (1997) reported lower catch rates of Atlantic herring in nets equipped with pingers compared to control nets in field trials and suggested that the herrings possibly reacted to the pinger sounds by avoiding the nets. Galician and Portuguese purse seiners mainly target European sardine, *Sardina pilchardus*, hereafter referred as sardine, and, to a smaller proportion, Atlantic horse mackerel, *Trachurus trachurus*, hereafter referred as horse mackerel, Atlantic mackerel (*Scomber scombrus*) and European anchovy (*Engraulis encrasicolus)*. Sardine is also the main target species of artisanal driftnet and beach seine fisheries (Galician Ministry of Fisheries, 2013; Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2013) and of great socio-economical importance for the local fishing communities and industries (Abaunza *et al*., 1995; Borges *et al*., 2003). However, no study has been conducted to date to assess the effect of pingers on sardines. Catch rates of horse mackerel were only analysed in two pinger surveys, where no negative effect was observed in bottom-set gillnet fisheries (Buscaino *et al*., 2009; Gönener and Özdemir, 2012).

Most fish species can detect sounds between 50 Hz to approximately 1.5 kHz but there are hearing specialists, such as some species within the taxonomic order of the clupeiforms, that are able to perceive sounds of up to 5 kHz (e.g. sea herrings, sprats, sardines, pilchards) or even in the ultrasonic range > 20 kHz (e.g. shads *Alosa* spp) (Mann *et al*., 2001; Popper and Schilt, 2008). These high-frequency hearing abilities are thought to be evolutionary adaptations to predation from echolocating cetaceans (Mann *et al*., 1997) that may have been developed particularly by shallow-water fish species (Popper *et al*., 2004). Sardine and horse mackerel are important prey species of cetaceans in coastal Iberian Atlantic waters (Silva, 1999; Pusineri *et al*., 2007; Santos *et al*., 2007; Sollmann, 2011; Méndez Fernández *et al*., 2012; Read *et al*., 2012; Santos *et al*., 2013). Although there is currently no evidence for ultrasonic hearing in sardine and horse mackerel, it is possible that these species may have developed such hearing specializations in response to echolocation clicks of preying cetaceans in the past. Consequently, they should also show avoidance reactions to commercially available pingers which emit pulses between 0.1 and 160 kHz, with harmonic frequencies up to 200 kHz (depending on pinger model).

Noise exposure can increase stress levels in fish being reflected in acute physiological and behavioural responses (Popper and Hastings, 2009). These responses enable the animal to compensate or adapt to a disturbance and to overcome threats, such as predation (Barton and Iwama, 1991).

Physiological stress responses in fish are expressed in immediate primary hormonal responses such as the release of corticosteroids (e.g. cortisol) and catecholamines into circulation, which give rise to secondary reactions including changes in plasma and tissue ion and metabolite levels, haematological features, and heatshock or stress proteins. This can finally lead to tertiary responses such as changes in growth, condition, disease resistance, reproduction, and ultimately survival (Barton, 2002). As in most fish cortisol reaches highest concentration one hour after being stressed (Iwama *et al.* 2006), cortisol tests are a good option in acute stress experiments (Martínez Porchas, 2009). Increased plasma cortisol concentrations in response to sounds have been observed in fish by Wysocki *et al*. (2006).

Behavioural responses of fish to sounds are often expressed through changes in swimming behaviour, including fish school compaction, sinking in the water column, increase in swimming speed and aversion of the sound source (Schwarz and Greer, 1984; Misund *et al*., 1996; Suuronen *et al*., 1997; Wilson and Dill, 2002; Kastelein *et al*., 2007). Fish with high-frequency hearing capacity, such as the American shad (*Alosa sapidissima*), showed a very rapid and directional response directly away from the sound source when exposed to simulated dolphin echolocation clicks (Mann *et al*., 1998; Plachta and Popper, 2003). Changes in fish school dynamics (e.g. schools becoming more compact or changing their relative position in the water column) are an adaptive feature for the avoidance of predators (Pitcher *et al*., 1996), such as cetaceans. While fish school compaction may increase catch rates, all other aversive reactions may potentially reduce fish catchability and consequently catch rates in purse seine and driftnet fisheries.

Therefore, the aim of the present study was to analyse the behavioural (changes in swimming behaviour) and physiological (differences in plasma cortisol concentration) stress response of captive wild sardines and horse mackerel to the sounds of three commercially available pinger models with different technical specifications (i.e. signal type, frequency range, source level, pulse duration and interpulse interval) in order to assess whether the use of pingers may have a negative effect on catch rates in fisheries directed at these species.

4.3 MATERIAL AND METHODS

Behavioural and physiological stress responses of fish were assessed in two separate experiments. Fish behaviour was recorded with an underwater video camera. Plasma cortisol concentrations were derived from blood samples of experimental fish.

Behavioural experiments were initially only planned with sardine, however, since a few horse mackerels were caught together with the live sardines, behavioural observations were also carried out for horse mackerel.

Since blood cortisol sampling implied the killing of test animals and only a limited number of fish was available, the physiological experiment was exclusively conducted with sardine and only one pinger model, the Fumunda F70 (Fumunda Marine).

Live fish handling and all experiments in this study were undertaken in Spain in full compliance with Spanish laws related to the protection and welfare of animals used for scientific studies.

4.3.1 CAPTURE, TRANSPORT AND ACCLIMATIZATION OF FISH

Live fish were caught by a purse seiner on the 11 May 2011 close to the Cies Islands (42°13'N/8°54'W) in the Ría de Vigo (Figure 4.1). In order to maximize the post-capture survival rate of the fish, the captain of the vessel was thoroughly instructed about the correct catching and handling procedure and provided with all necessary materials beforehand. The catch comprised about 200 sardines and six horse mackerels that were transferred into a seawater tank (720 l) and provided with oxygen (> 7 mg/l) during the transport.

On arrival in the fishing harbour of Vigo, the transport tank was lifted onto a pick-up and brought immediately to the aquaculture facilities of ECIMAT (Estación de Ciencias Mariñas de Toralla, University of Vigo, Isla de Toralla, Vigo) (Figure 4.1) where the fish were equally distributed into two cylindrical stocking tanks (Ø 1.36 m; 1500 l) filled with open-circuit pumped seawater (water temperature 15 – 17˚C), supplied with air and covered with a shade net to avoid that fish jump out of the tank.

Fish were acclimatized for 20 days in the stocking tanks before starting the experiments, since recovery from the acute stress of capture and transport can be expected within two weeks of acclimatization (Marçalo *et al*., 2008). The fish were kept at normal photoperiod and without any disturbance, except for water treatment, removal of dead animals and feeding twice a day. The tank water was initially treated with 200 ppm Formalin (40% solution of formaldehyde) to eliminate external fish parasites and to improve the microbiological profile of the tank water and the fish. This treatment was repeated once a week. In addition, a solution of Oxitetracyclin (50 ppm), a broad-spectrum antibiotic, was added to the tank water once every day during the first week of acclimatization as a preventive treatment against possible bacterial infections (James *et al*., 1988). Fish adapted well to the tank conditions and started feeding without any problems on day ten of the acclimatization period. They were initially fed with enriched *Artemia* spp (brine shrimp) and from day twelve on with pellets, starting with pellet size 150 µm until reaching pellet size 3.4 mm at day eighteen. Both, sardines and horse mackerels, started to swim in schools shortly after being introduced into the water tanks.

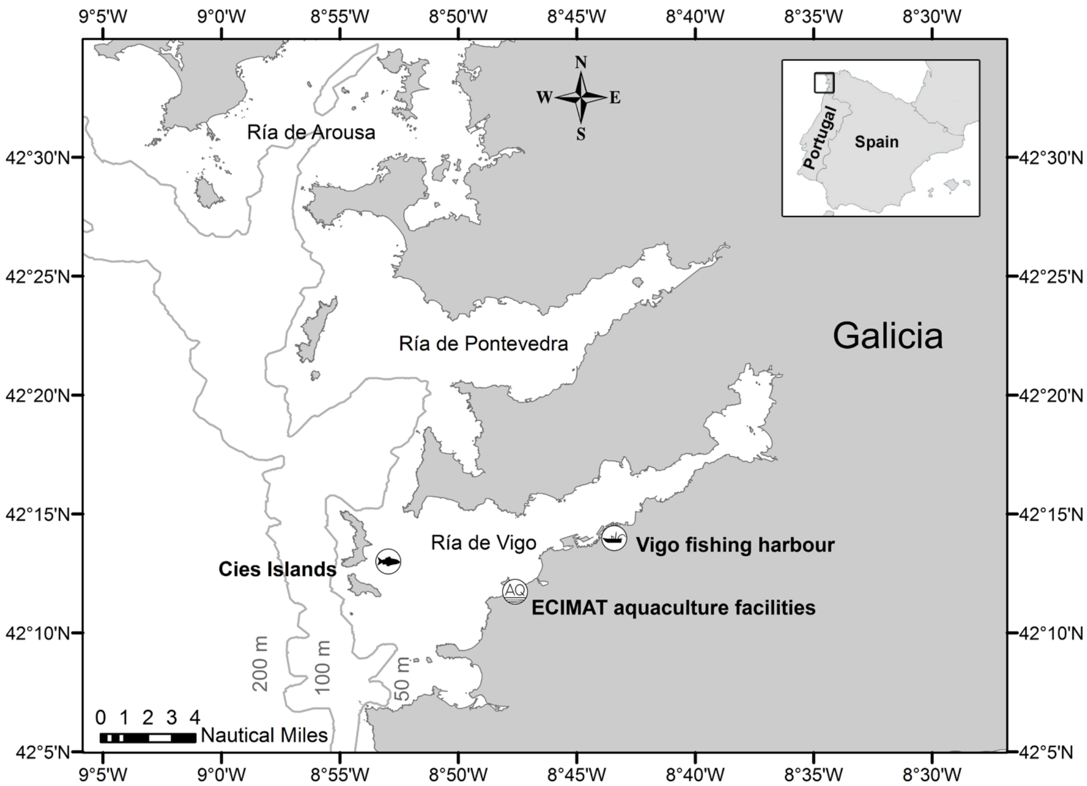


Figure 4.1. Map of the study area (Galicia, NW Spain). The *fish symbol* indicates the approximate location where live fish were caught.

4.3.2 SETUP AND PREPARATION OF TANKS

Behavioural and physiological experiments were conducted in separate tanks, as displayed in Figure 4.2. For the behavioural observations we selected a green, square-shaped tank (2 x 2 x 1 m; 4000 l) that allowed for suitable video images and provided enough space for the fish to school and swim in circles. A reference grid (370 square cells of 15 x 15 cm) for the distance measurements during the experiments was taped on the walls and bottom of the tank with white adhesive tape (1.9 cm wide) (Figure 4.3). Physiological experiments were conducted in the stocking tanks. The feet of all tanks were placed on polystyrene plates (thickness: 4 cm) to buffer sound propagation from the environment to the tank.

Figure 4.2. Set-up of experimental tanks in the laboratory.

4.3.5 BEHAVIOURAL EXPERIMENT

Research hypothesis: If the fish are stressed by the pinger sounds their swimming behaviour (school compaction, distance of fish school to bottom of the tank, swimming speed, aversion of sound source) should differ significantly between trials with active pingers and placebos, i.e. non-functional pingers.

After the acclimatization period, 30 sardines were transferred from the stocking tanks to the experimental tank and left there to acclimatize for another two days before experiments started. After finishing the behavioural observations with sardine, the same procedure was repeated with the six horse mackerels.

We tested the behavioural response of the fish to three different commercially available pinger models (Figure 4.3; see Table 4.1 for technical specifications).

The Marexi V2.2 and Fumunda F70 pingers produce tonal signals with constant duration and interpulse interval, the first emitting signals within the audible frequency range, and the latter in the ultrasonic range. The Aquamark 210 pinger operates in both, the audible and ultrasonic frequency range and it produces tonal and sweep signals with randomized duration and interpulse interval.

Figure 4.3. The three pinger models trialled (from left to right): Fumunda F70, Marexi V2.2, Aquamark 210.

Table 4.1. Technical specifications of the three pinger models trialled

	V2.2 (Marexi Marine Technology)	F70 (Fumunda Marine)	Aquamark 210 (Aquatec Subsea Ltd.)
Signal type	tonal	tonal	tonal & sweep signals
Source level (dB re 1µPa @ 1m)	132	145	150
Fundamental frequency (kHz)	10	70	5 - 60
Frequency spectrum	-	-	harmonics up to 160 kHz; extra-random frequency modulation
Pulse duration (ms)	300	300	randomized: 50 - 300
Interpulse interval (s)	4	4	randomized: 4 - 30

Each pinger model was tested 13 times (nine trials for sardine and four for horse mackerel). Between three and five sessions were conducted per day, using the different pinger models in random order and waiting at least one hour between sessions in order to make sure that fish returned to normal conditions. According to Kastelein *et al*. (2008) an inter-trial interval of two minutes is already enough to restore active behavioural reactions (such as startle responses) of fish to acoustic stimuli. When all sessions were finished, the fish were fed and not manipulated anymore until the next day.

Each session started with a 15 minute period during which the placebo was placed into the tank, followed immediately by a 15 minute period during which the active pinger was placed into the tank, emitting sounds. The sequence of placebo and active pinger exposure was not randomized, because using the active pinger first might have caused a prolonged effect on fish behaviour (in case the sounds are audible for the fish) that may have biased the behavioural reactions of fish in the subsequent placebo trials. The pingers were suspended from ropes about 20 cm from the pool wall, at about half way up the water column.

During each session, the fish behaviour was videotaped in continuous real-time video with a high-definition underwater camera (GoPro HD Hero 960), fixed with a bendable base at the tank wall at around 10 cm below the surface (Figure 4.4). The original curved lens of the underwater camera housing was replaced by a flat methacrylate lens to increase the definition of the camera images. To maintain sufficient light for the video images, the light over the experimental tank was switched on at least 30 minutes before the first session started. Additional to videotaping, the behavioural reactions of the fish were examined by eye and documented by an observer.

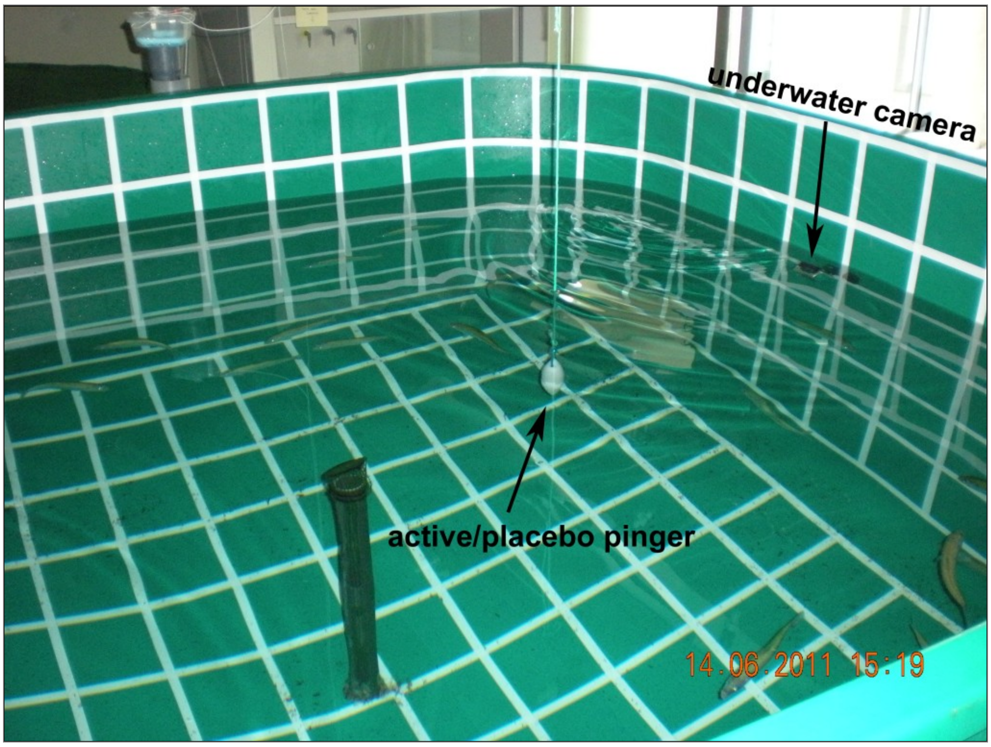


Figure 4.4. The position of the underwater camera and pinger/placebo in the tank during behavioural experiments.

4.3.4 PHYSIOLOGICAL EXPERIMENT

Research hypothesis: If the fish are stressed by the pinger sounds, the blood cortisol concentration of fish exposed to active pingers should be significantly higher than that of fish exposed to placebos.

Blood cortisol sampling was carried out in the morning, always at the same hour, leaving at least two days between each experiment in order to give the fish time to return to normal conditions.

In order to determine a control baseline plasma cortisol value of sardines for each experimental day, five fish were caught from one of the stocking tanks ("control tank"), before exposing them to the active pinger/placebo. The fish were caught with a handnet (all at once) and put into a bucket (20 l) with anaesthetic (300 ppm Phenoxyethanol) and air supply. While the fish were sedated, the pinger (either placebo or active pinger) was suspended into the other stocking tank ("test tank") and after one hour of exposure, five fish were retrieved from the test tank and sedated as described above. As most fish species show their highest plasma increase in cortisol within about 0.5 – 1 hr after a stressful disturbance (Barton and Iwama, 1991), an acute hormonal response in sardine should therefore be detectable after 1 hour of pinger exposure. Blood samples (1 ml) were taken from completely sedated fish (after three minutes) with heparinized syringes via caudal vein puncture (Figure 4.5a). Fish capture, sedation and blood withdrawal were carried out as fast as possible to avoid elevated stress levels through manipulation of fish. Afterwards, samples were centrifuged (10 minutes at 12 000 rpm) and plasma (transparent top layer) (Figure 4.5b) was frozen at - 80°C. Plasma cortisol was measured in defrosted serum samples by a Cortisol Enzyme Immunoassay Kit (Cortisol EIA Kit, Cayman Chemical Company, Ann Arbor, MI, USA), following the assay protocol included in the kit. The EIA plate was read with a microplate reader (Bio Rad 550) at a wavelength of 405 nm. Cortisol concentrations were converted from pg/ml into µg/dl for subsequent statistical analysis.

The active pinger and the placebo were tested alternately during different days, resulting in four replicates each. The two stocking tanks were used alternately as "control" and "test" tanks during the course of the experiment.

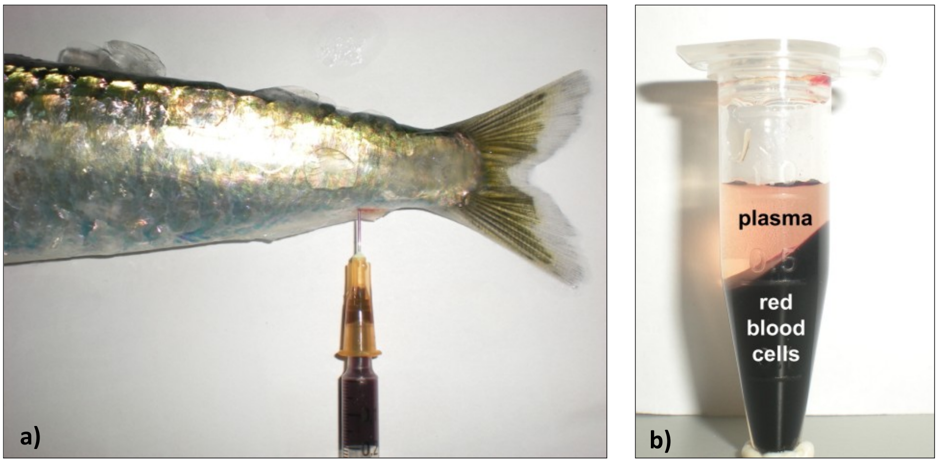


Figure 4.5 a) Caudal vein puncture for sardine blood withdrawal and **b)** plasma and red blood cell layers in centrifuged blood sample

4.3.5 BIOLOGICAL DATA OF SARDINE

Immediately after blood withdrawal sardines were measured (total length in cm), weighed (in grams) and killed by cutting their head off. Fish condition, i.e. fatness of a fish in relation to its length, was calculated following the equation for Fulton's condition factor as

$$K = 100*W/L^3$$

where W = whole body wet weight in g and L = total length in cm.

Fish with condition factor lower than the mean value ($\bar{x}$ = 0.8072) were classified as low-fat and fish with condition factor higher than the mean as high-fat fish.

Gonads were extracted from the dead fish and frozen at - 80°C for subsequent microscope and histological analysis. Sex and maturity were determined by visual observation (colour, texture and size) of fresh gonads and analysis of defrosted gonad tissue samples under the fluorescence microscope (Nikon Eclipse 90i), following the criteria of Simón Díaz (2009). For histological analysis, pieces of gonad were taken from every sampled specimen, fixed in Davidson´s solution (Shaw and Battle, 1957) and embedded in paraffin. Paraffin blocks were sectioned at 5 µm with a microtome. Tissue sections were deparaffinized, stained with Harris´ hematoxylin and eosin and examined by light microscopy.

4.3.6 DATA ANALYSIS

Analysis of video recordings

Video footage was processed using Avidemux 2.5, a free open-source program. A 10 minute sequence with the same start and end point (minute 5 - 15) was cut out of each 15 minute recording. A scan sampling technique was used, stopping the video sequence at 2, 4, 6, 8 and 10 minutes and determining the swimming parameters of fish on these screenshots.

Fish school compaction was measured as the distance between the fish closest to the bottom and the fish furthest away from it. The distance of the fish school to the bottom of the tank was measured as the distance of the snout of each fish to the bottom of the tank.

For the measurement of swimming speed (in $^{m}/_{s}$), five fish were selected from each screenshot, the video recording was run for three seconds in slow motion (one-half of original speed), and the distance swum by each fish was determined. The values for the five fish were averaged afterwards. Distances in the video images were measured using Small Measure v 1.0 (1 Hour Software), a small screen ruler to determine the number of pixels between two points on the screen, and converted into cm with the help of the reference grid on the tank walls.

Aversion of the sound source was quantified by stopping the video recording after 2, 4, 6 and 8 minutes and counting the number of fish concentrated on the tank wall opposite to the pinger/placebo during one minute in five seconds intervals, resulting in 48 counts for each video sequence.

All measurements were averaged for each video screenshot and trial.

Statistical analysis

Statistical analysis was performed with IBM SPSS Statistics 19 and, for Modelling, with Brodgar 2.7.2.

Mixed effects models provide a powerful tool to analyse unbalanced nested data, because they allow for the inclusion of fixed and random effects as well as for correlation between observations within the sampling unit (Zuur *et al*., 2009)

Our data were three-way nested because we sampled several fish during various video screenshots (behavioural experiments) / from two different tanks (physiological experiments) in multiple trials (repeated measures) and we therefore may expect correlation between the response variables within each sampling unit.

We first assessed whether random effects and a multiple variance structure (i.e. allowing for unequal variances) needed to be included into our model by visualizing the amount of variation of the fixed explanatory variables between video screenshots/tanks and between trials using conditional boxplots.

For response variables with Gaussian distribution we fitted a Generalized Least Square (GLS) model, including as many fixed explanatory variables and their interactions as possible, and compared this model with a Linear Mixed Effects (LME) model that additionally included the nested random effects "video screenshot/tank" and "trial" using the anova function. The model structure was:

Behavioural experiments:

Placebo-active pinger$_{ijk}$

Physiological experiments:

Control-placebo/active pinger$_{ijk}$ + Sex$_{ijk}$ + Maturity$_{ijk}$ + Condition Factor + Condition Factor$_{ijk}$ × Sex$_{ijk}$ + Condition Facor$_{ijk}$ × Maturity$_{ijk}$

where i = observation, j = video screenshot/tank and k = trial

Biological data were derived from dead fish and could therefore only be included into the models for physiological experiments since behavioural observations did not imply the killing of test animals.

We chose the best model, i.e. the one with the lowest value for the Akaike Information Criterion (AIC) and assessed whether the inclusion of a multiple variance structure of the fixed explanatory variables could improve the model by comparing the AICs of the previous model and a model containing the variance function VarIdent.

The response variable "aversion" followed a Poisson distribution and we therefore ran a Generalized Additive Model (GAM) with Poisson distribution and a log link function (without random effects) and compared the AIC to a Generalized Additive Mixed Model (GAMM), including random effects. The model with the lowest AIC was selected for subsequent model fitting.

To find the optimal model in terms of the fixed explanatory variables, we used likelihood ratio tests as we had factors with more than two levels. This procedure included fitting a full model, dropping all allowable terms in turn, applying Likelihood-Ratio-Tests of nested models, dropping the least significant term, and repeating the whole process until all terms were significant. We then validated the final model checking if the assumptions of homogeneity and independence of residuals were met, also checking for the existence of influential data points.

4.4 RESULTS

4.4.1 BIOLOGICAL DATA OF SARDINES

The biological data of the experimental sardines are summarized in Table 4.2. Only 5.3% of the fish were mature, while 40.8% were maturing and 53.9% immature. The sex ratio of female to male fish was 53:47. The mortality rate of fish was 5% during transport and 17.8% during acclimatization.

Table 4.2. Biological data of experimental sardines (n = 76)

	Mean	SD	Range
Total length (cm)	20.22	1.13	17.9 - 22.5
Weight (g)	67.37	12.53	45 - 112
Condition factor	0.81	0.08	0.57 - 1

4.4.2 BEHAVIOURAL REACTIONS OF FISH TO THE PINGER SOUNDS

There were no significant differences in mean distance to the tank bottom, swimming speed and the level of fish concentration on the tank wall opposite to the pinger between placebos and active pingers for any of the tested pinger models, neither for sardine nor for horse mackerel (Figure 4.6a,c,d).

Although differences were very small, the mean fish school height of sardines was significantly lower for the active Fumunda F70 pinger than for the placebo (GLS, $mean_{active}$ = 33.85 cm, $mean_{placebo}$ = 42.87 cm, t = -2.89; p = 0.005), while for horse mackerel, mean fish school height was significantly higher for the active Aquamark 210 (LME, $mean_{active}$=46.94 cm, $mean_{placebo}$=37.34 cm t=2.37, p=0.028) when compared to the placebo (Figure 4.6b).

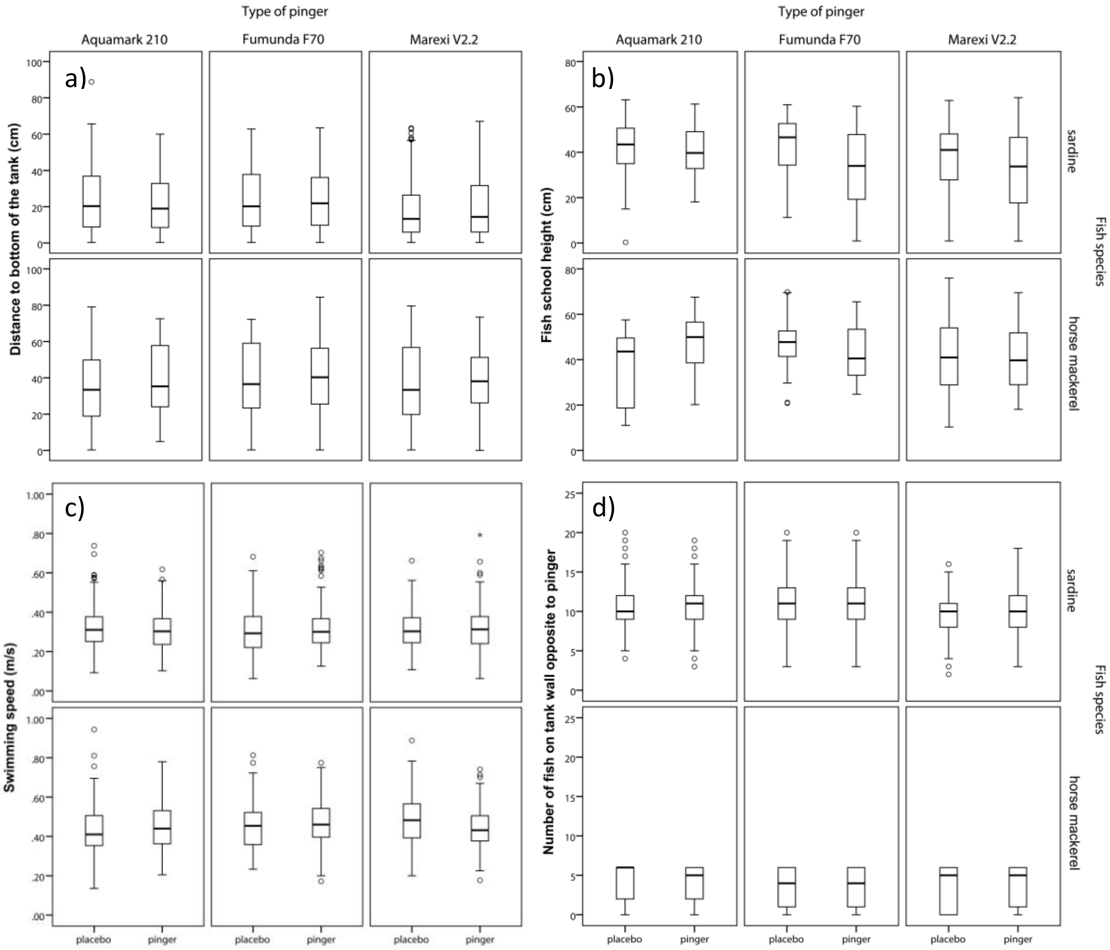


Figure 4.6. Boxplots representing differences in behavioural reactions of sardine and horse mackerel to three different models of active pingers and placebos, pooled across experimental trials: **a)** distance of fish school to the bottom of the tank, **b)** fish school height, **c)** swimming speed and **d)** aversive behaviour, i.e. concentration of fish on tank wall opposite to the pinger. The box stretches from the 25th to the 75th percentile. The line across the box represents the median values. The ends of the vertical line indicate the minimum and maximum data values. Individual points are considered outliers.

Differences in mean fish school height between active pingers and placebos varied greatly between trials for both, sardine and horse mackerel (Figure 4.7a,b).

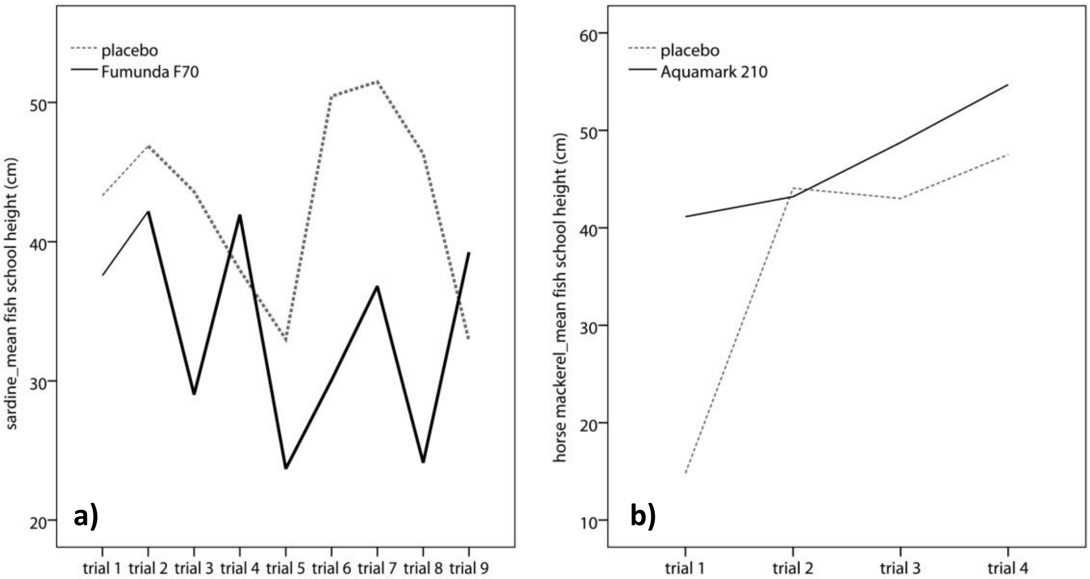


Figure 4.7. Line charts representing inter-trial differences in mean fish school height during active pinger and placebo exposure **a)** for sardine and the Fumunda F70 pinger and **b)** for horse mackerel and the Aquamark 210 pinger.

4.4.3 PHYSIOLOGICAL RESPONSE OF SARDINE TO FUMUNDA F70 PINGERS

Sardine plasma cortisol concentrations differed significantly before and after exposure to active Fumunda F70 pingers (GLS, $mean_{before}$ = 0.86 µg/dl, $mean_{after}$ = 1.42 µg/dl, $t = 3.61$; $p = 0.001$), while for the placebo no significant difference between pre- and post-values was detected (Figure 4.8).

The biological parameters condition factor, sex and maturity had no significant effect on the plasma cortisol concentrations.

As for behavioural parameters, inter-trial variability between pre- and post-exposure values was high (Figure 4.9).

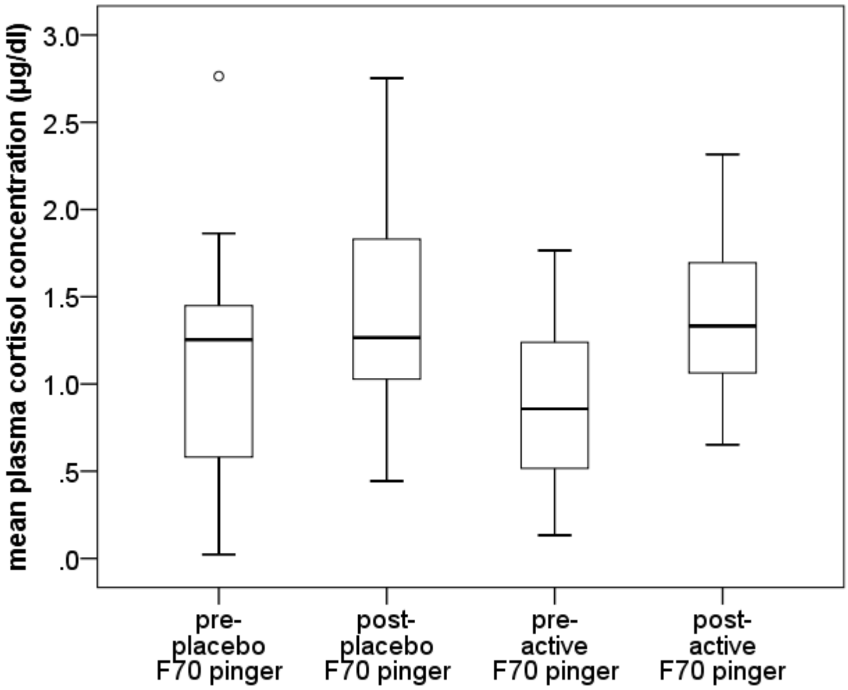


Figure 4.8. Boxplots representing plasma cortisol concentrations of sardine before (pre) and after (post) exposure to placebo and active Fumunda F70 pingers, pooled across experimental trials. The box stretches from the 25th to the 75th percentile. The line across the box represents the median values. The ends of the vertical line indicate the minimum and maximum data values. Individual points are considered outliers.

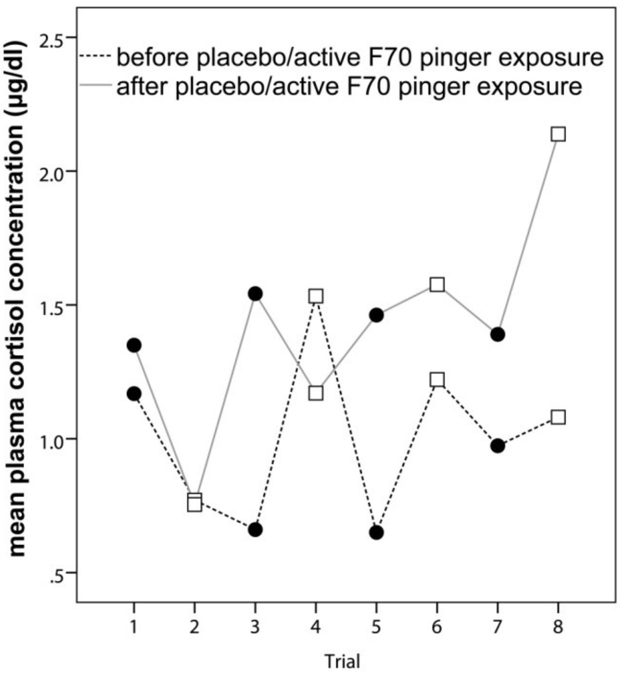


Figure 4.9. Line chart representing inter-trial differences in mean plasma cortisol concentrations of sardine before (*dotted line*) and after (*solid line*) exposure to placebo (*white squares*) and active (*black dots*) Fumunda F70 pingers.

4.5 DISCUSSION

4.5.1 INTERPRETATION OF BEHAVIOURAL AND PHYSIOLOGICAL RESPONSES OF FISH AND POSSIBLE BIAS

Although some significant effects of pingers on fish behaviour and plasma cortisol level were detected in our experimental survey, the responses of the fish to the pinger sounds were very subtle.

Of the four behavioural parameters observed, only fish school height (i.e. level of fish school compaction) showed significant differences between active pinger and placebo trials, the relative increase (Aquamark 210) and decrease (Fumunda F70) being only about 25%. This difference is relatively moderate when compared to the results of Marçalo (2009), where sardine group cohesiveness was observed to double and swimming speed showed a fivefold increase when fish were exposed to active stressors such as natural predators in an experimental tank. A similar pattern was observed for the hormonal stress level of sardines, where we found a slight, but significant increase in plasma cortisol concentrations after exposure to active Fumunda F70 pingers. The mean cortisol increment (0.56 µg/dl per hour) and the post-stress cortisol level (1.42 µg/dl) in our experiment was, however, very small when compared to the values reported by Marçalo *et al*. (2006) who measured a fivefold increase in mean cortisol concentrations in fish exposed to a stressor, corresponding to an increase rate of 6.9 µg/dl per hour and a post-stress value of 8.9 µg/dl. Our values are also well below the characteristic cortisol elevations of fish in response to acute stressors which, according to Wedemeyer *et al.* (1990) and Barton and Iwama (1991), tend to range between 3 - 30 µg/dl. Furthermore, base cortisol levels varied significantly between trials in our study, suggesting that differences in cortisol concentrations may also have been caused by environmental factors, such as changes in water temperature and salinity, or by the biological characteristics (e.g. condition, developmental stage) of the fish tested (Barton, 2002). Fish were held in open-circuit pumped seawater, were slight temporal variations in water temperature and salinity do naturally occur. Although we did not detect a significant effect of biological parameters on the mean base plasma cortisol concentration over the whole survey, they may be influential when inter-trial variance (five fish per trial) is analysed. However, by adding random effects to our model, inter-trial variance has already been taken into account. Fish handling may also introduce certain bias, since manipulation of fish, i.e. capture and blood withdrawal, provoke an immediate elevation of plasma cortisol that can be detected within 30 seconds of applying an acute stressor (Gerwick *et al*., 1999). The removal of single fish from the tank can also cause increased stress levels in the remaining fish which may increase basal cortisol concentrations in subsequent experiments (Laidley and Leatherland, 1988). As the risk for handling stress can be minimized by rapid blood withdrawal of anaesthetised fish (Pottinger *et al*., 1992; Olsen *et al*., 1995), we made sure that fish were captured from the tank all at once within a few seconds, introducing them immediately into the sedation basin and taking blood samples as soon as animals were fully anaesthetised. By leaving at least two days between consecutive trials, our experimental fish were assumed to be able to return to their cortisol base levels, which should usually already be achieved within six hours from an acute stress (Iwama *et al*., 2006). Although handling effects cannot be completely ruled out in our survey, it is unlikely that they had a significant effect on our results since sampling procedure was identical for all trials and possible bias introduced through handling should consequently be the same for active and placebo pinger trials.

Against this background, the behavioural and physiological reactions observed in our experiments are likely to be caused by environmental and biological factors rather than reflecting acute stress responses. In addition, even if fish responded with school cohesion to the pinger sounds, as in the case of sardine, this would not have a negative effect on catch rates since fish would be more concentrated and therefore probably easier to catch in a real fishing scenario.

The lack of significant observable and measurable reactions of the fish to the pinger sounds in our survey indicates that sardine and horse mackerel do not perceive the pinger signals a as a sign of imminent danger. The known hearing range of horse mackerel and sardine is between 0.1 and 2 kHz (Kastelein *et al*., 2008; Popper and Schilt, 2008), although, being a member of the subfamily Clupeinae, sardine may be able to hear sounds up to about 4 or 5 kHz, as demonstrated for scaled sardine *Harengula jaguana* and round sardinella *Sardinella aurita* by Mann *et al*. (2001). Therefore the Aquamark 210 pinger, that also emits low frequency sounds down to 5 kHz, may potentially be audible for the fish, at least for sardines. However, even though the fish may be able to detect pinger sounds in the audible or even ultrasonic range, the source level (< 150 dB re 1 mPa) and pulse repetition rate (maximum 15 pulses/minute) of the sounds emitted by all pinger models tested in our survey are probably not high enough to cause aversive reactions. According to Popper *et al*. (2004), agitated responses of clupeid fish, leading to movement away from the sound source are usually not observed until the ultrasound gets more intense (175 – 184 dB re 1 mPa). In addition, Wilson *et al*. (2011) found that allis shad (*Alosa alosa)*, another clupeid fish, only reacted to ultrasound clicks with a repetition rate of at least 20 clicks/second, suggesting that a single ultrasonic click may be detected, but not necessarily be interpreted as danger. Signal duration needs to be at least 500 ms in order to make it detectable for fish (Hawkins, 1981).

4.5.2 THE FEASIBILITY OF PINGER USE IN GALICIAN AND PORTUGUESE FISHERIES

With the aim to reduce incidental catches of cetaceans in community waters, pinger use became obligatory in specific fishing areas (including Atlantic waters of Spain and Portugal) within the European Union for fisheries operating bottom-set gillnets, entangling nets and driftnets since 2004 (EC Council Regulation 812/2004; see **Section 1.7.2**). In addition, Member States are encouraged to monitor and assess the effect of pingers by means of scientific studies. This regulation, however, only applies for vessels > 12 m and does therefore not include artisanal net fisheries, which make up the bulk of Galician and Portuguese fisheries (Galician Ministry of Fisheries, 2013; Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2013). Moreover, pingers are not mandatory in purse seine fisheries. Information on the efficiency of pingers in these fisheries and their effect on catch performance is therefore limited.

Nevertheless, the preliminary results of recent field trials in Portuguese purse seine fisheries indicate that the use of Fumunda F70 and F10 (similar technical specifications as the Marexi V2.2) pingers can significantly reduce interactions with common dolphins (Vingada *et al*., 2011). In California, common dolphins could be successfully deterred from driftnets with Dukane NetMark 1000[11] pingers without any apparent effect on catch rates (Barlow and Cameron, 2003; Carretta and Barlow, 2011). All three pinger models emit short pulses (300 ms) at a constant interpulse interval (4 s) and a relatively low source level (132 – 145 dB re 1 mPa), the Fumunda F10 in the audible frequency range, the Fumunda F70 in the ultrasonic spectrum and the Dukane NetMark 1000 covering both spectra.

Moreover, there are positive results from pinger trials in fisheries negatively affected by interactions with bottlenose dolphins. In Mediterranean artisanal bottom-set gillnet and trammel

[11] **Dukane Seacom Inc., St. Charles, USA**

net fisheries, Aquamark 210 pingers reduced bottlenose dolphin-net interactions by 70% (Brotons *et al*., 2008b). Gear damages by bottlenose dolphins was significantly reduced with DDD02[12] pingers (Buscaino *et al*., 2009) and Aquamark 100 pingers (Gazo *et al*., 2008) in the Mediterranean (by 31% and 85%, respectively) and with SeaWave High Impact Saver[13] pingers (Gönener and Özdemir, 2012) in the Black Sea (70% reduction). In all studies, catch rates (inter alia of *T. trachurus*) were higher in pinger nets than in control nets, suggesting that pinger use did also significantly reduce depredation on catch. All pingers tested in these studies operate at a moderate source level (145 – 160 dB re 1 mPa), the Aquamark 100 only in the ultrasonic range and the remaining models in both, the audible and ultrasound spectrum (from 0.1 up to 200 kHz). While the Aquamark and SeaWave pingers produce short pulses (50-900 ms) with a random interpulse interval (4 - 30s), the DDD02 emits longer pulses (6s) with a constant interpulse interval of 100s. Bottlenose dolphins also showed aversive behaviour to Aquamark continuous and responsive pingers during field trials in Ireland (Leeney *et al*., 2007; Berrow *et al*. 2008), whereas no such effect was observed on common dolphins. These pingers were especially developed for their use in trawl fisheries and have similar technical specifications as the other commercially available Aquamark models, except for a higher source level (165 dB re 1 mPa). While the continuous pinger emits continuous signals, the responsive pinger only activates when receiving cetacean clicks in its vicinity.

Apart from potential side effects on fisheries target species, pingers are also frequently suspected to have an impact on cetacean behaviour as long-term pinger exposure may cause habituation (Dawson *et al*., 1998) or even sensitisation (Richardson *et al*., 1995), i.e. the active attraction of the cetaceans to the pinger sounds. Although this theory has recently been refuted for common dolphins in a long-term (19 years) study with Dukane NetMark 1000 pingers by Carretta and Barlow (2011), the inquisitive bottlenose dolphins are thought to have a higher risk to habituate to the pingers (Cox *et al*., 2003). In addition, widespread pinger use may also involve the risk that cetaceans, especially species with more sensitive hearing such as harbour porpoise, may be excluded from their habitat or even suffer hearing damage (Culik *et al*., 2001; Gordon and Northridge, 2002).

[12] **STM Ltd. and SEAMed Ltd., Verona, Italy**

[13] **SeaWave, Delft, The Netherlands**

4.6 CONCLUSIONS

Summarizing the positive and negative pinger aspects discussed above, an "ideal pinger" should allow for maximum deterrence of the cetacean species targeted, while exerting minimum negative impact on non-target cetaceans and fisheries resources (Reeves *et al*., 2001). Therefore, the source level of the pinger sound should be loud enough to cause aversion in cetaceans, but not excessively loud to avoid habitat exclusion and hearing damage. The likelihood of habituation may be mitigated by reducing the duration of sound exposure, either through long interpulse intervals (Reeves *et al*., 2001) or the use of responsive pingers (Leeney *et al*., 2007) and by periodically changing the sound frequency emitted by the pingers (Gazo *et al*., 2008). Of the pinger models tested in our survey, only the Aquamark 210 displayed randomized frequency modulation, pulse duration and interpulse intervals.

In addition, to preclude the audibility of pinger sounds by targeted fish, a high frequency range (≥ 10 kHz), moderate source level (< 160 dB re 1 lPa @ 1 m), low pulse repetition rate and a short pulse duration (< 500 ms) are recommended features (Plachta and Popper, 2003; Kastelein *et al*., 2007; Wilson *et al*., 2011).

Apart from these technical characteristics, the choice of pinger also largely depends on the scope of application (i.e. fisheries affected and cetacean species involved) as well as on practical aspects, such as the ease of operation and price of pingers. Therefore, as a next step, fishery-specific long-term field trials should be conducted in our study area with the active co-operation of affected fisheries, to assess pinger efficiency and the magnitude of possible side effects on non-target cetaceans and fish species, as well as the willingness of local fishers to accept this mitigation tool.

CHAPTER 5

Experimental fishing with an "umbrella-and-stones" system to reduce interactions of sperm whales with bottom-set longlines

This chapter includes work from the following publication:

Sabine Goetz, Martín Laporta, Julio Martínez Portela, María Begoña Santos and Graham John Pierce. 2011. Experimental fishing with an "umbrella-and-stones" system to reduce interactions of sperm whales (*Physeter macrocephalus*) and seabirds with bottom-set longlines for Patagonian toothfish (*Dissostichus eleginoides*) in the South West Atlantic.
ICES Journal of Marine Science 68 (1): 228-238.

The main author's contribution to this publication included sampling design, data processing and analysis (data were provided by a fisheries observer), and publication writing.

5.1 ABSTRACT

Depredation, i.e. damage or removal, of Patagonian toothfish (*Dissostichus eleginoides*) from longlines by sperm whales (*Physeter macrocephalus*) can cause considerable economic loss for Spanish fishing vessels in the South West Atlantic. The fishery also suffers high bycatch rates of seabirds. The main goal of the study was to assess the extent of depredation and seabird bycatch and to test the potential of the so-called "umbrella" system, coupled with attached stones for faster sinking, for minimizing both. Moreover, we investigated the relationships between sightings of sperm whales, depredation, catches, and environmental variables using generalized additive modelling. Data were collected during 297 hauls on a longliner in 2007/2008 in international waters of the South West Atlantic. Sperm whales were sighted during 35% of the hauls, always during gear retrieval, and their presence was positively related to fish damage. The overall depredation rate (0.44% of the total catch) was low, but is assumed to be underestimated because sperm whales were suspected of also taking fish without leaving visual evidence. The "umbrella-and-stones" system was highly effective in preventing bycatch and appeared to restrict depredation, but significantly reduced catches. The results demonstrate there is still some way to go to solve the problem of depredation.

5.2 INTRODUCTION

The large-scale fishery for Patagonian toothfish (*Dissostichus eleginoides*) began in the early 1990s (Lack and Sant, 2001), following the decline in fish stocks off Chile and in many Northern Hemisphere fisheries. In 1992, the total reported catch of the Patagonian toothfish reached 40 710 t worldwide (FAO, 2003), and the fishery developed into an important and highly valuable one, with reported annual catches (1995-2001) of between 28 035 and 44 047 t (1995–2001) (FAO, 2003; Laptikhovsky and Brickle, 2005). In 2007/2008, the total landings of toothfish were 12 573 and 10 291 t within and outside the CCAMLR (Commission for the Conservation of Antarctic Marine Living Resources) Convention Area, respectively (STECF, 2009).

Two types of longline gear are used in the toothfish fishery around the Falkland/Islas Malvinas: (i) the MUSTAD autoline system, which utilizes lines made up of 250 m sections, with snoods (short hook lines with baited hooks) connected with crimps and swivels at 1.2 – 1.4 m intervals, and (ii) the "Spanish system", which utilizes two lines, a fishing line and a safety line, and two winches for hauling. The longline fishery takes place year-round at fishing depths of 650 – 2000 m.

The Patagonian toothfish is a long-lived, slow-growing notothenid endemic to Antarctic and Subantarctic waters (Agnew, 2004) and distributed from 36°39' to 55°S in water temperatures of 2 - 12°C. Concentrations of the species are found south and northeast of the Falkland/Malvinas, over the shelf break of Buenos Aires Province and between Burdwood Bank and Staten Island. Toothfish vary in size by depth (depth range 80 – 2500 m), with adults (> 80 cm) living below 900 m (Prenski and Almeyda, 2000).

The species is commercially very valuable, reaching market prices averaging US$ 14 per kilogram (J.A. Novo, captain FV "Arnela", pers. comm.). Damaged fish are usually discarded because only immaculate specimens can be sold. Cetacean depredation, i.e. the damage and removal of hooked fish and bait from the fishing gear, can, therefore, lead to considerable economic loss for longline fisheries if it reaches significant levels. Depredation has been widely reported for this fishery, primarily involving the sperm whale (*Physeter macrocephalus*; Ashford *et al*., 1996; Kock, 2001; Hucke Gaete *et al*., 2004; Purves *et al.*, 2004; Kock *et al.*, 2006; Pin and Rojas, 2007; Moreno *et al.*, 2008).

Sperm whales are the largest toothed whales, with mature males recorded up to 21 m long (Berzin, 1971). They have a complex social organization in which groups of young males ("bachelor" groups in different stages of sexual maturation) and solitary sexually mature males spend most of the year separated from groups of females and calves, migrating to higher latitudes in spring/summer and returning to lower latitudes in winter; females and calves remain in low latitudes year-round (Berzin, 1971). Sperm whales are found in deep waters of all oceans, and results from many studies (originally based on analysis of stomach contents of animals killed commercially and more recently on stranded specimens) indicate a diet based largely on deep-sea cephalopods of various size, followed by fish (see Kawakami, 1980; Rice, 1989; Santos *et al*., 1999). Korabelnikov (1959), Clarke (1980), and Abe and Iwami (1989) reported the presence of Patagonian toothfish in the diet of sperm whales in the Southern Ocean.

Cetaceans seem to be particularly attracted to longlines because large and easily accessible prey is provided (Capdeville, 1997), and the sounds of the engine, electronic equipment, and the hauling noise of the longline vessels can be used as a cue to locate food (Thode *et al*., 2007). When preying on longline catches, sperm whales are thought to rip the fish from the line, leaving only the lips and jaws on the hooks, or to remove the entire fish (Ashford *et al.*, 1996; Purves *et al.*, 2004). Depredation occurs primarily during gear hauling (Nolan *et al*., 2000; Purves *et al*. 2004), most likely because it is easier for the whales to feed on the catch during hauling than deep-diving to remove the fish during gear soaking (Gilman *et al.*, 2006a).

Sperm whales may occasionally become entangled in the longline and cause breakage of the line (Kock *et al.*, 2006), but they are rarely entrapped. Bycatch of seabirds, however, is a much bigger conservation issue in this fishery, mostly affecting albatrosses and petrels (Ashford *et al.*, 1995; Moreno *et al.*, 1996). When the longlines are set, birds are frequently hooked or entangled while feeding on the bait, being dragged underwater and drowned as the gear sinks (Gilman *et al*., 2005). The area in and around the Falkland/Malvinas supports seabird populations of international importance (Woods and Woods, 1997) and, according to Gales (1993), population declines of several albatross species have been linked to longline fisheries in the Southern Ocean. Consequently, many[14] species of albatross and petrel have been listed under the Agreement on the Conservation of Albatrosses and Petrels (ACAP), negotiated under the United Nations Convention on the Conservation of Migratory Species of Wild Animals (CMS) in 2004, to stop or reverse population declines by mitigating known threats to these species.

There are several approaches to avoid or reduce interactions with sperm whales and seabirds (Gilman *et al.*, 2005, 2006a). Vessels might, for instance, try to avoid fishing areas where sperm whales and seabirds concentrate. However, these areas tend usually to also be the richest fishing grounds, and navigating to alternative fishing areas inevitably results in additional costs for fuel and loss of fishing time. Other strategies to keep cetaceans/seabirds away from the longline include the use of deterrents or to reduce the detectability of the baited hooks, the gear, and the vessels. This can, for instance, be achieved by dying the bait blue (seabirds) or by reducing vessel/hauling noises to a minimum (cetaceans).

In the fishery for Patagonian toothfish, there have been several attempts in recent years to reduce interactions by limiting the cetacean and seabird access to catch and bait. Pin and Rojas (2007) and Moreno *et al*. (2008) used mammal excluder devices (MEDs), also known as an

[14] **In August 2010, the figure was 29 species (see http://www.acap.aq/)**

"umbrella system" or "Chilean longline", which consist of cone-shaped umbrella-like net sleeves that protect the hooked fish from depredation during hauling. To deter seabirds, CCAMLR Conservation Measure 25-02 of 2005[15] requires vessels using the autoline or Spanish system to deploy weights on hook lines to allow for a faster sinking rate and, as a consequence, to minimize the bycatch of seabirds by reducing the time the bait remains at the surface.

The main goal of the present study was to assess the extent of depredation by sperm whales on catches and cetacean/seabird bycatch in a scientifically, largely unexplored fishing area, and to test the potential of different longline designs, including "umbrellas" and stone weights, to minimize depredation and the bycatch of seabirds. Moreover, we investigated how sightings of sperm whales, depredation, and catch rates are related to each other and to environmental and fishery-related variables.

5.3 MATERIALS AND METHODS

Data were collected by an experienced fisheries observer on-board the Spanish large-scale longlining vessel "Arnela", which targeted mainly Patagonian toothfish between 23 November 2007 and 7 April 2008. Fishing took place in two areas outside the Falkland Islands Inner (FICZ) and Outer (FOCZ) Conservation Zones: (i) area AI46 (extending east of the Argentinean EEZ between 41 and 48°S and up to 56°W), and (ii) area AI54 (bordering Falklands/Malvinas waters to the west and extending between 53 and 55°S and to 50°W). To investigate spatial trends, the study area was divided into 25 subareas of 1 × 1°. The fishing effort for each subarea is shown in Figure 6.1.

[15] **CCAMLR Conservation Measure 25-02 of 2005** on the minimisation of the incidental mortality of seabirds in the course of longline fishing or longline fishing research in the Convention Area

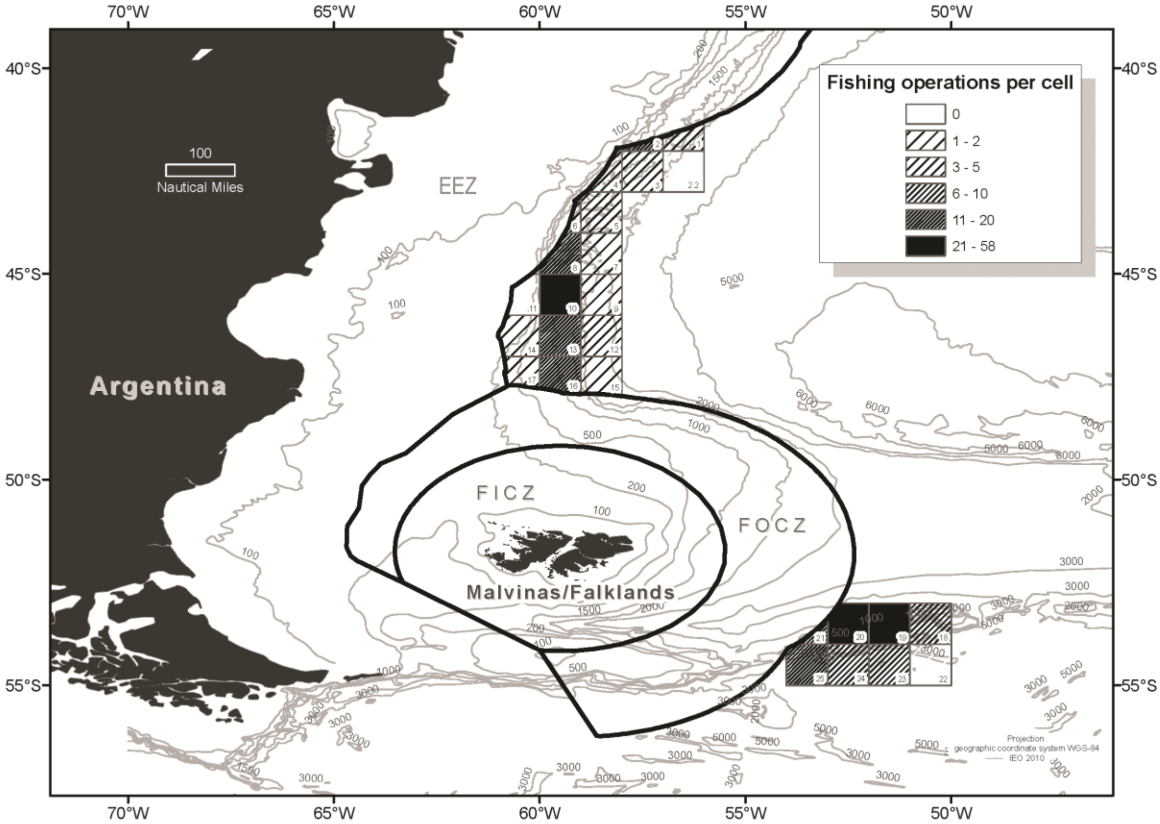
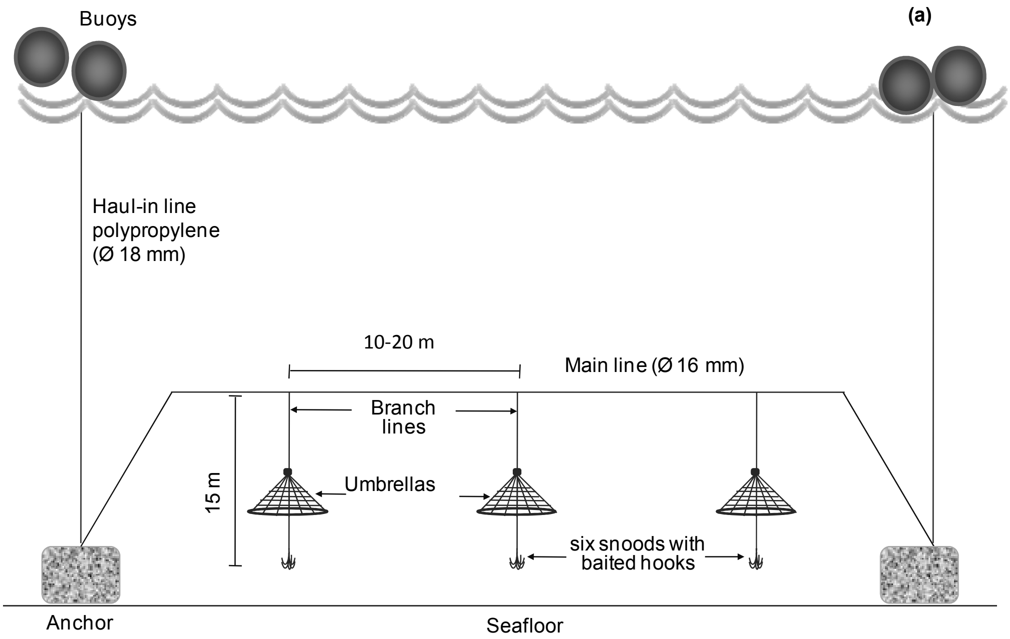


Figure 5.1. Study area and the fishing effort by subarea. The limits of the Falkland Islands fisheries Inner (FICZ) and Outer (FOCZ) Conservation Zones and of the Argentine Exclusive Economic Zone (EEZ) are marked by *bold lines*. The main bathymetry is indicated.

5.3.1 LONGLINE DESIGN AND EXPERIMENTAL SETTING

The experimental longline design tested in our study is similar to that used by Moreno *et al.* (2008). The method originated in the Chilean artisanal toothfish fishery (Moreno *et al.*, 2006), where it was used to minimize depredation, and was adopted with some modifications by the large-scale longline fleet in Chile for the same reason. In each experimental longline, the single monofilament hook line was replaced by a polypropylene main line carrying several branch lines. The distance between branch lines varied between 10 and 20 m (depending on vessel speed during longline setting). Each branch consisted of a polypropylene line (diameter, Ø, 8 mm) supporting six snoods with baited hooks, a stone (≈ 8 kg) to weigh down the branch line and increase sink speed, and an "umbrella". The bait used during the study was mostly sardine (*Sardina pilchardus*). Each umbrella was composed of an upper and a lower ring (Ø 10 and 80 cm, respectively) supporting a cone-shaped net sleeve of length 1.5 - 2 m in length (Figure 5.2a). The rings and the net were positively buoyant in the water, allowing the umbrella to float over the baited hooks while the gear was soaking. When the main line is hauled back during gear retrieval, the net sleeve slides down, covering the hooked toothfish (Figure 5.2b). As depredation is believed to take place primarily during gear retrieval, it was assumed that this mechanism could protect hooked fish from sperm whales and reduce damage to the catch.



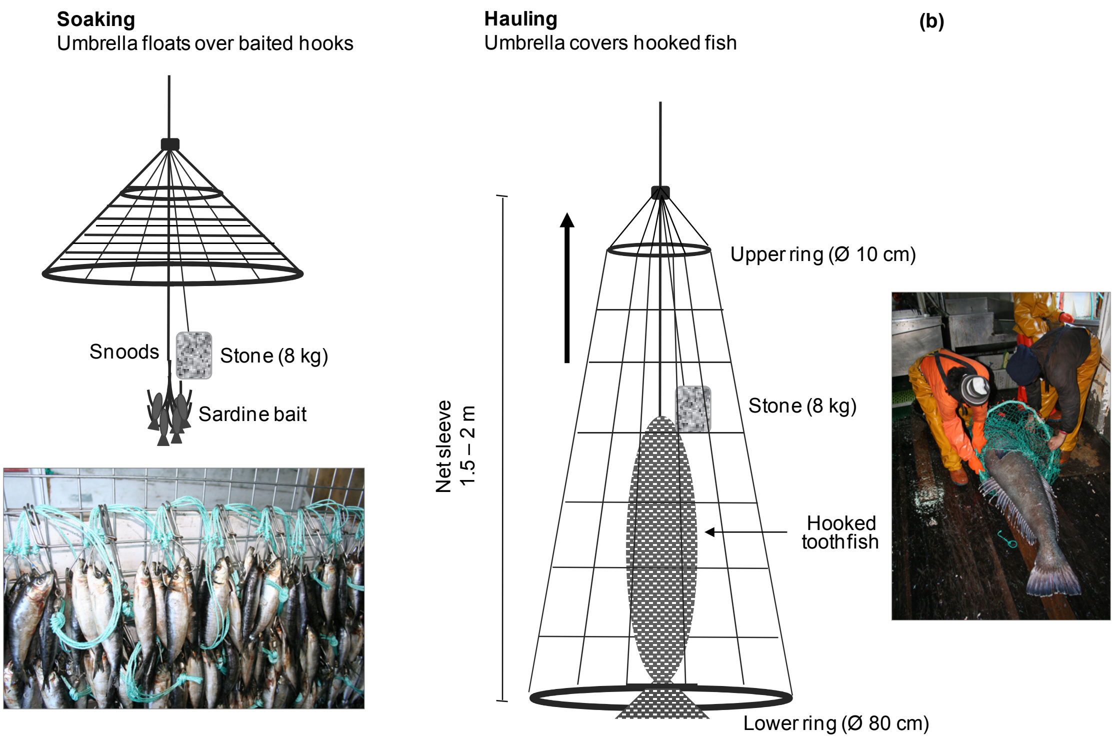


Figure 5.2. a) Experimental longline setting and **b)** the umbrella design and mechanism.

We tested four umbrella designs during the study, modifying the material of the rings and the length of the net sleeve. During fishing operations, either all (complete coverage), two-thirds, or one-half (partial coverage) of the branch lines carried umbrellas. This resulted in eight experimental longline settings (G1 – G8), varying in the proportion of hooks covered by umbrellas and the combination of different umbrella types (Table 5.1).

Table 5.1. Experimental longline settings (different umbrella designs used and their arrangement on the longline).

Arrangement of umbrellas on the longline		Umbrella design
Complete hook coverage		
G1	1 – 2 – 1 – 2 – 1 – 2 – 1	0 = no umbrella
G2	2 – 2 – 2 – 2 – 2 – 2 – 2	1 = metal rings; net sleeve length: 1.5 m
G3	4 – 4 – 4 – 4 – 4 – 4 – 4	2 = rope rings; net sleeve length: 1.5 m
		3 = rope rings; net sleeve length: 1.7 m
Two-thirds of hooks covered		4 = rope rings; net sleeve length: 2.0 m
G4	2 – 3 – 0 – 2 – 3 – 0 – 2	
One-half of hooks covered		
G5	2 – 0 – 2 – 0 – 2 – 0 – 2	
G6	2 – 0 – 3 – 0 – 2 – 0 – 3	
G7	2 – 0 – 4 – 0 – 2 – 0 – 4	
G8	4 – 0 – 4 – 0 – 4 – 0 – 4	

5.3.2 DATA COLLECTION AND ANALYSIS

During each set, the on-board observer recorded the start/end time of gear setting/retrieval, fishing location, number of branch lines, experimental longline setting used, amount (in kg and number of individuals) of each species caught, sea surface temperature (SST), sea state (Douglas scale), windspeed, moon phase, cloud cover, sightings of cetaceans (species and number observed) and seabirds (species only), depredation on catches (occurrence and number of fish damaged), and bycatch of seabirds and cetaceans (Table 5.2). In addition, the vessel captain registered toothfish catches and sightings of sperm whale for each segment of the longline in a logbook. Each segment consisted of 25 branch lines and was marked with coloured plastic tags.

Table 5.2. List of variables and their descriptors used for analysis.

Variables	Descriptor
Fishery data	
Toothfish (*D. eleginoides*) catch	CPUE (kg of fish per hook) Number of fish
Number of branch lines/hooks	
Soak time	min
Duration of gear retrieval	min
Depth of gear retrieval	m
Gear design used	Four umbrella designs (1 – 4) Complete/partial hook coverage Eight experimental longline settings (G1 – G8)
Sighting	
Sperm whale (*P. macrocephalus*) sightings	Presence/absence of sperm whales Number sperm whales
Depredation	
Depredation on toothfish	Occurrence of depredation Number fish damaged
Environmental/oceanographic data	
Sea state	Douglas scale: 0–9
Cloud cover	Scale: 0–8
Moon phase (M)	M1: new moon M2: waxing moon M3: full moon M4:waning moon
Sea surface temperature (SST)	°C
Time of day	Day/night

After each haul, evidence of depredation was assessed by counting the number of toothfish damaged by sperm whales. A toothfish was considered as having been damaged by a sperm whale if it was missing body parts and displayed crushed tissue with typical blunt tooth marks (Figure 5.3 a-f). Photos were taken of damaged fish to facilitate identification of bite marks.

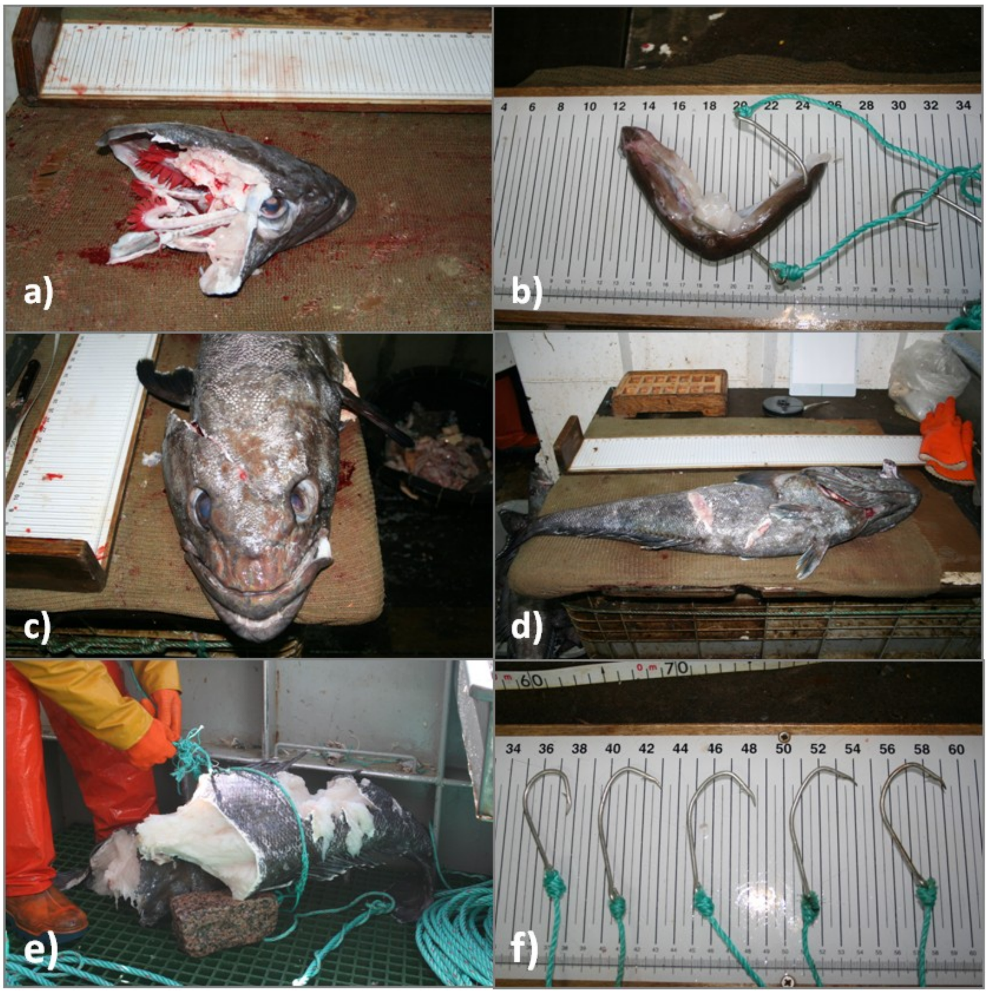


Figure 5.3. Evidence of sperm whale depredation on toothfish **a)** only head or **b)** lips left on the hook, **c)** fractured cranium, **d)** blunt tooth marks, **e)** missing body parts and crushed tissue, and **f)** bent fishing hooks

As sightings of sperm whales by both the observer and the captain were opportunistic, we combined both datasets for analysis. Catches of toothfish were transformed into CPUE (catch per unit effort), expressed as kilogram of fish per hook.

It is very likely that sperm whales remove an unknown number of fish entirely from the longline. Consequently, taking into account only fish damaged, may underestimate the real level of depredation. Therefore, we compared the CPUE for sets with/without sperm whale presence and evidence of depredation using the non-parametric Mann-Whitney-U-Test, assuming that a significant, visually undetectable removal of fish from the line would be reflected in smaller catches. To assess whether sperm whales really remove whole hooked fish directly from the line during retrieval, we analysed whether the presence of sperm whales close to the vessel had an immediate effect on catches. For this purpose, the sums of fish caught on the longline segments before and after a sperm whale sighting were compared applying the Mann-Whitney-U-Test. The five segments before and after the sperm whale sighting were coded as −5, −4, −3, −2, −1, 0, +1, +2, +3, +4, and +5, with 0 representing the segment when the sperm whale was first seen. The number of fish was then summed for the 5, 4, 3, 2, and 1 segments before/after the 0 segment, and then compared pairwise.

To assess how the presence of sperm whales, depredation, catch rates, and environmental and fishery-related variables are related to each other, we used generalized additive models (GAMs; Hastie and Tibshirani, 1990; Zuur *et al*., 2007). The response and explanatory variables are listed in Table 5.2. Before running the models, we explored the data following the protocol of Zuur *et al.* (2007, 2009). We checked all explanatory variables for collinearity and excluded one from every pair of collinear variables from the subsequent analysis. To reduce the influence of small numbers of large values, the variables CPUE of toothfish and soak time were square-root transformed. One sample was omitted from the analysis because of its extreme values for number of branch lines and duration of retrieval. The variables sea state and cloud cover were treated as continuous variables in the analysis, resulting in better models, i.e. higher percentage of variance explained, than using them as nominal variables. The nominal variable moon phase was coded using dummy variables according to the scheme of Zuur *et al*. (2007), allowing for a stepwise comparison of one moon phase with all other moon phases.

Response variables followed Gaussian (continuous data), Poisson (count data), or binomial (presence/absence data) distributions. Continuous explanatory variables were entered into the model as smoothers, and the maximum number of degrees of freedom (k) was restricted to 4 to avoid over-fitting and selecting biologically unrealistic models. Models were fitted using backward selection, sequentially excluding individual variables to identify the model which would result in the lowest AIC (Akaike Information Criterion). Having thus removed one variable, the process was repeated until all remaining terms were significant or none remained.

We used the Mann-Whitney-U-Test to determine which of the four different umbrella designs resulted in the highest catches. For this purpose, the number of fish caught per set with each umbrella type was standardized for a mean number of branch lines and then averaged.

All GAMs were run in Brodgar 2.6.5 (www.brodgar.com); the Mann-Whitney-U-Tests were performed using Minitab 15.

5.4 RESULTS

5.4.1 FISHING EFFORT AND CATCH

In all, 297 hauls were carried out in water depths of 600 - 2200 m ($\bar{x}$ = 1264 ± 283). Each longline carried between 900 and 3000 hooks ($\bar{x}$ = 1794 ± 480) and was left to soak in the water for 3 – 67 hours ($\bar{x}$ = 20.67 ± 11.22 h). Fishing effort in zones AI46 and AI54 were 336 414 (62.8 %) and 199 500 (37.2 %) hooks, respectively. In all, 61 t of toothfish were caught during the whole study, 65% in area AI54. The CPUE varied for the different subareas, with values highest in areas 1, 2, 10, and 25. The highest CPUE was obtained in depths of 1000 - 1600 m.

5.4.2 CETACEAN AND SEABIRD SIGHTINGS

Sperm whales (Figure 5.4) were sighted during 104 of 297 longline sets (35%) and exclusively during gear retrieval. The proportion of hauls with sperm whale present was 37.4% for area AI46 and 32.9% for area AI54. The number of sperm whales sighted per haul ranged between one and six animals, and they were usually swimming alone (72%), or in groups of two (16%) or three (10%). Sightings of sperm whales were most numerous in subareas 2, 5, 8, 14, 19, and 25 and in depths of 1000 - 1400 m. Other cetacean species observed were minke whales (*Balaenoptera acutorostrata*), long-finned pilot whales (*Globicephala melas*), killer whales (*Orcinus orca*), dusky dolphins (*Lagenorhynchus obscurus)*, and Southern right whale dolphins (*Lissodelphis peronii*). The seabirds sighted consisted of several species of albatross, petrel, and shearwater (Table 5.3).

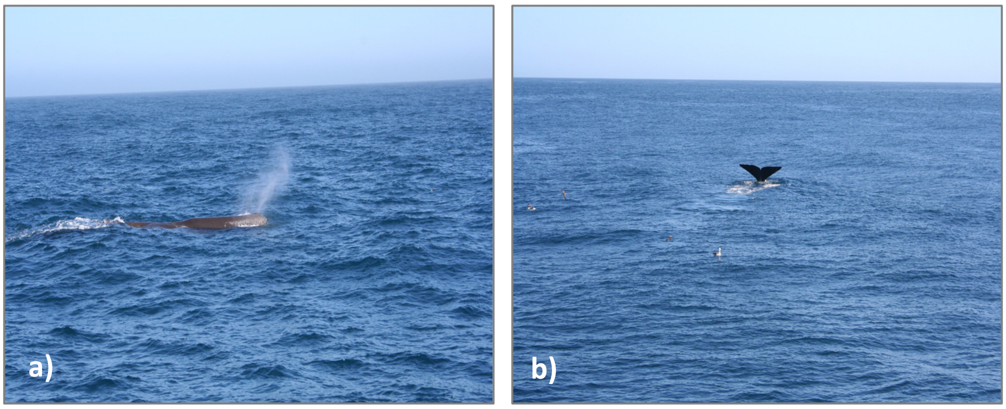


Figure 5.4. Sperm whale sightings: a) sperm whale breathing at the surface and b) tail fluke of sperm whale during submersion.

Table 5.3. Sightings of cetaceans (sighting frequency, species, and number of individuals sighted) and seabirds (species sighted only).

Scientific name	Common name	Sighting frequency	Number of individuals
Cetaceans			
Physteridae			
Physeter macrocephalus	sperm whale	104	1 – 6
Balaenopteridae			
Balaenoptera acutorostrata	common minke whale	3	1
Delphinidae			
Globicephala melas	long-finned pilot whale	2	3 – 15
Orcinus orca	killer whale	1	4
Lagenorhynchus obscurus	dusky dolphin	1	> 200
Lissodelphis peronii	Southern right whale dolphin	1	5
Seabirds			
Diomedeidae			
Diomedea exulans	wandering albatross		
Diomedea epomophora	Southern royal albatross		
Thalassarche chrystostoma	grey-headed albatross		
Thalassarche melanophrys	black-browed albatross		
Procellariidae			
Macronectes giganteus	Southern giant petrel		
Macronectes halli	Northern giant petrel		
Daption capense	cape petrel		
Procellaria aequinoctialis	white-chinned petrel		
Puffinus puffinus	manx shearwater		
Puffinus gravis	great shearwater		
Hydrobatidae			
Oceanites oceanicus	Wilson's storm petrel		
Fregetta tropica	black-bellied storm petrel		

5.4.3 DEPREDATION BY SPERM WHALES ON CATCH

Evidence of depredation on the catch was found in 24 longline sets (damage rate 8%). Usually just 1 – 2 fish were damaged, but depredation was occasionally as much as five fish per set. Most of the toothfish damaged by sperm whales were hauled with only the head or the lips left on the hook or displaying multiple fractures in the cranium. If fish were covered with umbrellas during hauling, observed evidence of depredation by sperm whale mainly consisted of missing body parts and crushed tissue with typical blunt tooth marks. Some fish hooks were observed bent, indicating that bait or hooked fish had been torn off the hook by force (see Figure 5.3).

Sperm whales were seen in proximity of the vessel during 71% (17 sets) of depredation events. In other words, out of the 104 sets where sperm whales were present, 87 sets (84%) had no evidence of damaged catch. When evidence of depredation was detected, between 1.5 and 17.2% ($\bar{x}$ = 6.6 ± 4.4%; n = 23) of the total toothfish catch was damaged per set. On one occasion, the whole catch was damaged, but consisted only of a fish. The overall depredation rate, i.e. the ratio of damaged fish in all sets to the total number of fish caught during the whole study, was 0.44% (39 out of 8885 toothfish).

All the pairwise comparisons of the numbers of fish hooked on the longline segments before and after the 0 segment, i.e. the segment where sperm whales were first sighted, indicated significant differences. The most significant difference was found when the two segments (W = 5180.5; $p < 0.001$) and three segments (W = 3116; $p < 0.001$) before and after the appearance of sperm whales were compared, suggesting that sperm whales take hooked fish entirely from the line and that fish damage we recorded is an underestimate of total depredation. We found no significant difference in CPUE when we comparing sets with/without evidence of depredation (W = 40 414; p = 0.52) and sets with/without presence of sperm whales (W = 28 344; p = 0.56), suggesting no significant reduction in overall catch rates even if sperm whales remove fish entirely from the line.

5.4.4 FACTORS AFFECTING SIGHTINGS OF SPERM WHALES, CATCH RATES, AND DEPREDATION ON CATCH

The GAM revealed that sperm whales were more frequently sighted close to the vessel by day than by night, and more often during a waxing moon than during other moon phases (Table 5.5).

Another factor found to influence the frequency of sightings of sperm whales was SST, with the lowest frequency of sightings in water temperatures ≈ 8°C and highest frequency at ≈ 11°C (Table 5.4, Figure 5.5a).

The CPUE of toothfish was related to duration of gear retrieval, gear design, SST, the number of sperm whales sighted, and the depth of gear retrieval (Table 5.4). It increased linearly with longer retrieval times and was higher for partial coverage of hooks. Moreover, the CPUE exhibited a minimum at SST ≈ 8 – 9°C, decreased with increasing numbers of sperm whales around the vessel, and increased with water depth up to 1200 m, after which it decreased (Figure 5.5 b-d).

The GAM results showed that evidence of depredation on catch was highly positively related to the presence of sperm whales (Table 5.5). In addition, we detected a positive linear trend between the frequency of depredation and sea state (not shown). No relationships were found between depredation and the CPUE or the duration of gear retrieval. The number of fish damaged showed a strong relationship with the number of sperm whales sighted around the vessel, first increasing with larger numbers of sperm whales, then remaining relatively stable if more than three sperm whales were in the vicinity (Table 5.5, Figure 5.4e). There were fewer damaged fish when the CPUE was high (> 0.5 kg per hook; Table 5.5, Figure 5.4f). Moreover, the quantity of fish damaged increased with sea state until state 6, then dropped again in rough conditions (Table 5.5, Figure 5.5g).

Table 5.4. GAM results (n = 296 sets). The response variables presence/absence of sperm whales and occurrence of depredation both followed a binomial distribution, whereas a Gaussian distribution was appropriate for the CPUE of toothfish and a Poisson distribution for number of fish damaged. The results displayed are: explanatory variables included in the final model, whether they were included as smoothers (S) or nominal variables (N), their significance (based on χ^2, F, or t tests, with the value of p) and the direction (sign) of the effect (+ or –). D.f. are the estimated degrees of freedom of the examined smoothers. D.f. = 1 implies a linear effect, and values > 1 indicate a progressively stronger non-linear effect. Also given are the overall percentage of deviance explained (%dev) and the AIC value for the model. For explanatory variables used, see list of variables (Table 5.2). For the variable gear design, only the descriptor of complete/partial coverage of hooks was considered in the model.

Response variables	**Explanatory variables**	**Type**	**z / F / χ^2**	***p*-value**	**sign**	**d.f.**	**%dev**	**AIC**
Presence/absence of sperm whales	Day/night	N	3.69	0.0002	+		12.3	341.48
	M1	N	–3.22	0.0013	–			
	M2	N	–2.70	0.0069	–			
	M3	N	–2.70	0.0060	–			
	SST	S	14.64	0.0020		2.89		
Toothfish cpue	Duration of gear retrieval	S	10.72	0.0012		1.00	15.4	–354.53
	Complete/partial hook coverage	N	–2.83	0.0050	–			
	SST	S	5.25	0.0054		2.05		
	Number of sperm whales	S	4.76	0.0116		1.81		
	Depth of gear retrieval	S	3.17	0.0376		2.23		
Occurrence of depredation	Presence/absence of sperm whales	N	4.79	< 0.0001	+		10.3	155.46
	Sea state	S	6.91	0.0086		1.00		
Number of damaged fish	Number of sperm whales	S	39.60	< 0.0001		2.11	22.4	233.28
	Toothfish CPUE	S	17.59	0.0004		2.84		
	Sea state	S	17.21	0.0003		2.33		

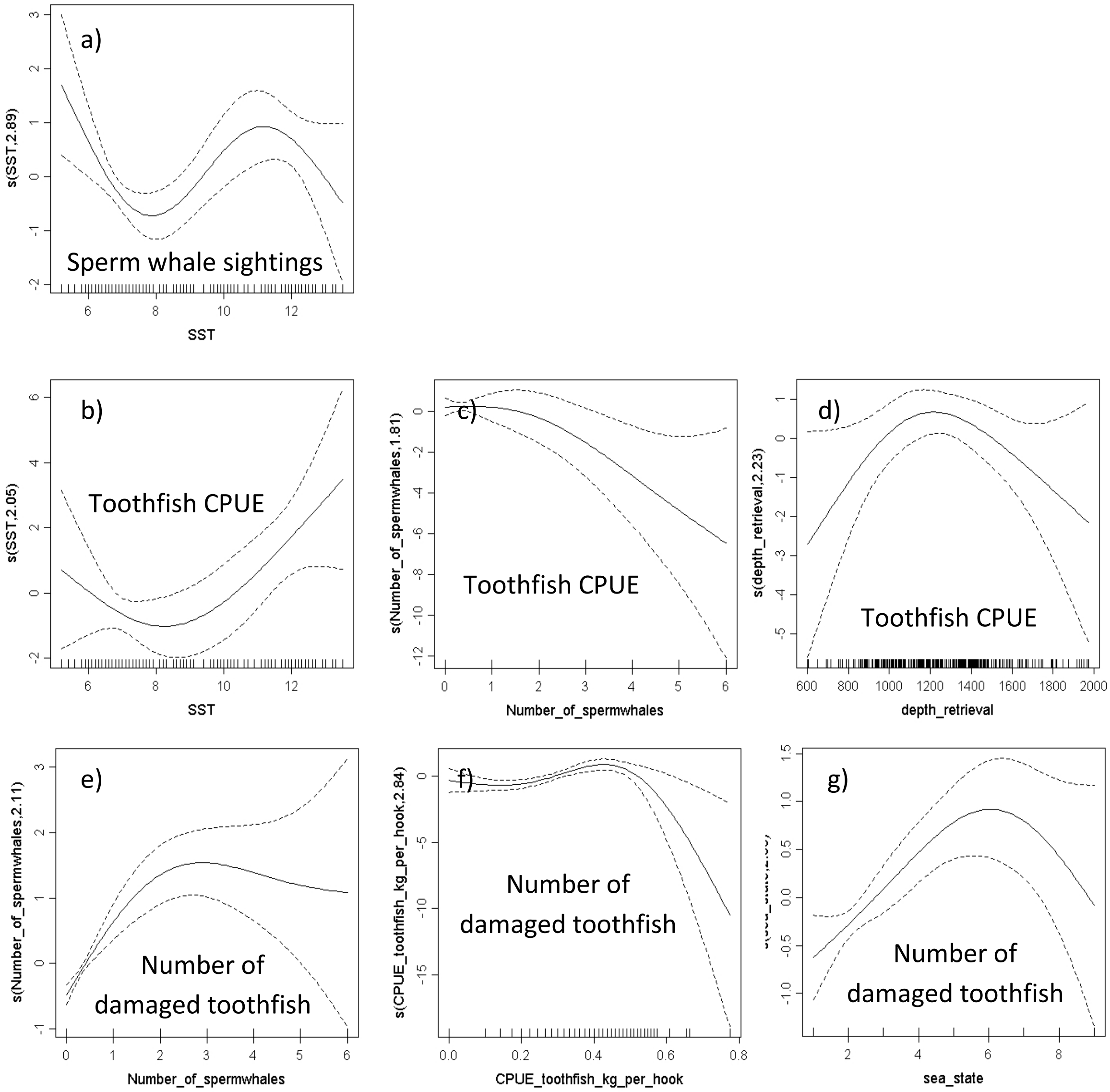


Figure 5.5. GAM results: smoothing curves for partial effect of a) SST (°C) on sperm whale sightings; b) SST (°C), c) number of sperm whales, and d) depth of gear retrieval (m) on toothfish CPUE; e) number of sperm whales, f) toothfish CPUE, and g) sea state on number of toothfish damaged. The y-axis indicates the partial additive effect that the explanatory variable on the x-axis has on the response variable. The numbers in the parenthesis indicate the estimated degrees of freedom (also displayed in Table 5.4). The influence of a variable increases as the values on the y-axis depart from zero. Dotted lines indicate 95% confidence bands.

5.4.5 THE IMPACT OF "UMBRELLA" DESIGN AND EXPERIMENTAL LONGLINE SETTING ON CATCH AND DEPREDATION RATES

The Mann-Whitney-U-Test demonstrated that hooks with no coverage from umbrellas caught more fish than hooks that were covered. Comparing the different umbrella designs, designs 1, 2, and 4 yielded better catches than design 3, but there were no significant differences in catch rates between designs 1, 2, and 4 (Table 5.5).

Table 5.5. The Mann-Whitney-U-Test comparing catch rates (number of fish caught) for different umbrella designs: 0 = no umbrellas; 1–4 = different umbrella designs.

Pairwise comparison of catch rates **First sample > second sample** **(Confidence level = 95.00)**	**W**	***p*-value**
0 > 1	34 067	0.0001
0 > 2	63 982	< 0.0001
0 > 3	41 409	< 0.0001
0 > 4	44 849	< 0.0001
1 > 3	3 964	< 0.0001
2 > 3	36 197	0.0008
4 > 3	12 949	< 0.0001

When comparing the eight experimental longline settings, we found that settings with partial hook coverage had a higher CPUE than settings with complete coverage (GAM: $t = -2.83$; $p = 0.0050$; %dev = 15.4; AIC = –354.53). Among the three settings with complete coverage (G1 – G3), there were no significant differences in catch rates. Of the settings with partial coverage, G5 and G8 achieved significantly higher CPUE than the other settings (G5 > G6: $t = 2.41$; $p = 0.0166$; G5 > G7: $t = 2.83$; $p = 0.0050$; G8 > G4: $t = 2.28$; $p = 0.0012$; G8 > G6: $t = 4.0$; $p < 0.0001$; G8 > G7: $t = 2.57$; $p = 0.0108$; %dev = 17; AIC = 359.19).

There were no significant differences in the records of depredation between the two levels of hook coverage or between the eight longline settings. Depredation was low for longline settings G1, G6, and G8, and there was no depredation registered for settings G2 and G4 (Figure 5.6).

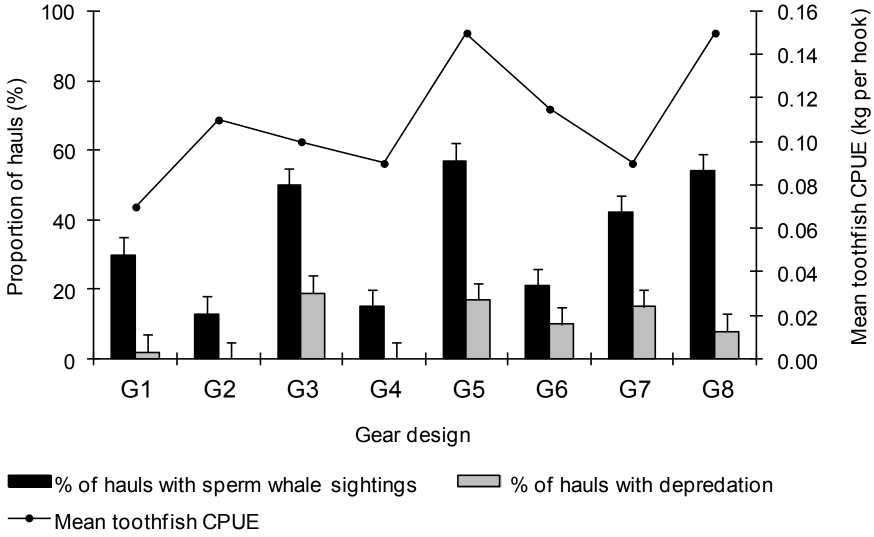


Figure 5.6. Proportion of hauls (*n* = 297) with sightings of sperm whales, evidence of depredation, and mean toothfish CPUE for different gear designs.

5.4.6 BYCATCH OF CETACEANS AND SEABIRDS

There was no bycatch of seabirds and cetaceans during normal fishing operations over the whole study period. One seabird, a black-browed albatross (*Thalassarche melanophrys*), was caught accidentally on a longline when some of the stone weights were not attached correctly to the line and became detached and sank, leaving the baited hooks floating at the surface for a period (Figure 5.7).

Figure 5.7. Black-browed albatross bycaught when stone weight became accidently detached from the longline.

5.5 DISCUSSION

5.5.1 SIGHTINGS

All cetacean and seabird species sighted during the survey are common in the cold marine ecosystem of the South West Atlantic (Northridge, 1984; Moore *et al*., 1999; Croxall and Wood, 2002; White *et al.*, 2002; Gandini and Seco Pon, 2007).

Sperm whales were by far the most frequently sighted cetacean species in the proximity of the vessel. They were mostly seen as solitary individuals, but groups of two or three animals were also observed. Similar group sizes were reported by Purves *et al.* (2004) and White *et al.* (2002) in South West Atlantic waters. The large-scale distribution of the sperm whales depends primarily on that of their major prey, i.e. cephalopods, and suitable conditions for breeding. In the South West Atlantic, they are mainly found in the warm waters of the Brazil Current off Brazil and Uruguay, where cephalopods are more abundant (Berzin, 1971). Nevertheless, sperm whales do follow their prey along warm, deep currents into higher latitudes, concentrating in areas where warm currents reach into cooler waters (Kirpichnikov, 1950). Our study area, particularly area AI46, directly borders the Brazil–Malvinas Confluence (BMC) zone. This region, recognized as one of the high-energy zones in the world, is characterized by the confluence between the warm, saline Brazil Current that flows south, and the cold, fresh Falkland/Malvinas Current, which flows in the opposite direction (Olson *et al*., 1988). The area is a transition zone inhabited by a mixture of subtropical and subantarctic organisms (Boltovskoy, 1986) and is rich in fishery resources.

Sperm whales are thought to feed primarily on meso- and bathypelagic cephalopods, squid being of much greater importance than octopus (Akimushkin, 1955; Rice, 1989). Fish are an important component of the diet in some areas, e.g. off Iceland (Martin and Clarke, 1986), in the Gulf of Alaska, and the East Bering Sea (Okutani and Nemoto, 1964). The most common fishes recorded in the diet have been demersal species that, in some cases, could attain large size (1 – 3 m long; Berzin, 1971). Kawakami (1980) reported 68 species of fish belonging to 49 families in his review of the diet of sperm whales. Sperm whales exhibit a strong preference for deep water with steep depth gradients (Davis *et al.,* 1998), and feeding dives are mostly to depths between 400 and 800 m (Watkins *et al*., 1993; Amano and Yoshioka, 2003).

According to Huecke Gaete *et al.* (2004) and Purves *et al.* (2004), sperm whales are likely to be attracted to fishing areas with high catch rates. In our study, we did not find a positive relationship between catch rates and the frequency of sightings of sperm whales, but sightings and toothfish catch increased towards warmer water and were concentrated in areas with mean water depths of 1000 - 1600 m. This indicates that sperm whales are likely to be found in areas with high density of toothfish, though if the sperm whales preyed regularly and directly on toothfish close to the seafloor, they would have to exceed their common diving range considerably. Therefore, the distribution of sperm whales might be determined instead by the distribution of their principal prey, squid, or perhaps they may congregate in areas where toothfish are usually caught, i.e. feeding primarily on hooked fish during longline retrieval.
We also found that sightings of sperm whales were more common by day than by night, a finding also reported by Purves *et al.* (2004). This result may, however, be simply attributed to the fact that sighting probability is much less at night because of the lack of light; nocturnal sighting frequency may, therefore, be underestimated in our study.

Another factor that seems to affect the frequency of sightings of sperm whales was moon phase, with most sightings during the waxing moon. Many cephalopod species exhibit some level of light-induced diel vertical migration, moving to the surface at night and returning to deeper water at dawn (Roper and Young, 1975). Therefore, the sperm whales in our study might have foraged closer to the surface during the waxing moon, resulting in a greater sighting frequency during that moon phase. However, the lack of any impact of lunar cycle on foraging success by day, found by Whitehead (1996), does not support this theory.

5.5.2 DEPREDATION ON CATCH

As sperm whales were present in proximity to the vessel in almost three-quarters of the depredation events, they are assumed to be the main predators on hooked toothfish. They were sighted exclusively during longline hauling and, in addition, the number of fish caught on the longline was significantly less immediately after the appearance of sperm whales close to the vessel. It is, therefore, highly likely that depredation takes place while the gear is being hauled and not while it is soaking on the seafloor. As longlines were usually set in depths of > 1000 m, sperm whales probably prefer to feed on hooked fish close to the surface instead of deep-diving for it. Gear-hauling took, on average, 5.85 hours in our study, and significantly increased in duration (up to 12 hours) when the CPUE of toothfish was high. Consequently, sperm whales would have plenty of time to feed on catch. The sound of the hydraulics might serve as a cue to the start of hauling, consistent with the observations of Ashford *et al.* (1996) and Purves *et al.* (2004), who suggested that sperm whales take fish off the line close to the surface. In addition, Straley *et al.* (2002) reported that some sperm whales showed evidence of depredating on the line, e.g. grooved indentations along the side of the head apparently caused by a line running through their mouth.

The characteristics of damaged fish are similar to those described by Ashford *et al.* (1996), Purves *et al.* (2004), and Pin and Rojas (2007) in previous studies, identifying the sperm whale as the main predator on hooked toothfish. This assumption is also supported by the significant positive relationship we found between the occurrence of depredation and the presence of sperm whales around the vessel.

Damage and depredation rates in our study were low. The damage rate (the percentage of longline sets with evidence of depredation) was less than that reported by Pin and Rojas (2007) for longlines equipped with MEDs, i.e. 16% of sets with depredation. The overall depredation rate (the percentage of fish damaged during all longline sets) is similar to the rates found by Moreno *et al.* (2008) with MEDs (0.5%) and lower than the rate found by Hucke Gaete *et al*. (2004) without MEDs (1.73%). Although we found no significant difference in CPUE from sets with/without visual evidence of depredation, we have to consider that CPUE decreased when there were more sperm whales around the vessel. This suggests that sperm whales may actually have a negative impact on catch rates, particularly if they attack the longlines in large groups. If we consider that, on most occasions when sperm whales were sighted around the vessel, depredation was not evident by visual observation, this finding supports our hypothesis that a considerable amount of the depredation remains undetected. We also discovered that depredation and the number of fish damaged were positively related to sea state. As hauling usually takes longer in rough seas, sperm whales might have more time to prey on the hooked fish than when the weather is calm. Sea states 7–9 were only registered in 3% of all hauls, so there were insufficient observations to make a clear statement about depredation levels under very rough sea conditions.

Kock (2001), Purves *et al*. (2004), and Pin and Rojas (2008) mention that sperm whales occasionally take 80% and more of the catch in a single set. In our study, the maximum percentage of fish damaged per set was < 20% (except the set where the whole catch was one fish), indicating that the umbrellas are most likely efficient in preventing sperm whales from taking a large part of the catch from the longline. However, damage and depredation rates in our study are most likely underestimated because only fish damaged were considered as lost.

5.5.3 THE ECONOMIC LOSS THROUGH INTERACTIONS WITH SPERM WHALES

Even though the average loss attributable to damaged fish appears to be small, the financial loss to fishers may be significant because of the high market value of toothfish and the likelihood that some depredation goes unrecorded. Moreover, steaming to alternative fishing areas in order to "escape" from the sperm whales results in additional expense for fuel and loss of fishing time.

5.5.4 IMPACT OF GEAR DESIGN ON CATCH RATES, DEPREDATION, AND BYCATCH

Hooks covered with umbrellas caught fewer fish than uncovered hooks, and CPUE was higher for longline settings with partial hook coverage than for settings with complete coverage. In a comparable study by Moreno *et al.* (2008), in contrast, the use of MEDs had no adverse effect on catch rates. In our experimental setting, the umbrellas were knotted to the branch lines, whereas Moreno *et al*. (2008) attached them in such a way that the sleeves could slide up and down the branch line during setting and hauling.

Comparing the different umbrella designs, designs 1, 2, and 4 yielded better catches than design 3. Of the different longline settings with partial hook coverage, G5 and G8 delivered the highest CPUE. Both settings included only one type of umbrella, in contrast to settings G4, G6, and G7 that combined different umbrella types, a fact that might increase the stability of the gear in the water and reduce entanglement of the net sleeves. There was no depredation for settings G2 (complete coverage) and G4 (two-thirds of hooks covered). However, small sample size is an issue in those cases, because the number of observations for those longline settings was very low compared with the other settings. Among the settings that reduced depredation most efficiently, G8 had the highest catch rates and might, therefore, be the most appropriate of the settings tested.

The attachment of stone weights to the branch lines proved to be highly efficient in minimizing incidental bycatch of seabirds. The fast sink speed of the longline during setting prevented the birds from feeding on the bait and, consequently, getting hooked on the line and drowning.

5.5.5 SUCCESS OF THE "UMBRELLA-AND-STONES" SYSTEM

Clearly, the "umbrella-and-stones" system was effective in preventing bycatch of seabirds and marine mammals. The effectiveness of umbrellas in reducing sperm whale depredation on catch, however, was not very evident in the study, although some results indicate that, given an appropriate umbrella design, they might be useful in preventing sperm whales from taking large quantities of catch from the longline. Nevertheless, they could not prevent depredation completely. Material costs for the umbrellas are relatively low, and if the fishers build them themselves, production costs can be reduced. Moreover, they can be used for a long time, and if umbrellas prove to reduce depredation on catch, they are a reasonable investment that could eventually pay off. However, we have to bear in mind that umbrellas reduced catch significantly in our study, so their negative effects might undermine their benefits.

Modifications to the umbrellas, such as allowing the net sleeve to move along the branch line (as in the study of Moreno *et al*., 2008) or reducing the visibility of the umbrellas in the water, might help to improve the catch rates. Fishers and longline associations should be encouraged to become active participants in the improvement of existing longline designs and the development of new designs.

CHAPTER 6

General Discussion

GENERAL DISCUSSION

This PhD thesis aimed to provide new insights into interactions of cetaceans with Spanish and Portuguese fisheries. Different research methodologies were used to assess interactions in small-scale and large-scale fisheries operating in national and distant Atlantic waters (the SW Atlantic). The present work identifies hotspots (marine areas/fisheries) for cetacean-fishery interactions and provides information about the types and scale of interactions in the surveyed fleets, as well as on their consequences for fishers and cetaceans. In addition, the suitability of different strategies to mitigate cetacean-fishery interactions is evaluated and discussed on a fishery-specific level. The main results and conclusions of this dissertation, as detailed below, can help to reduce operational cetacean-fishery interactions in Spanish and Portuguese fisheries and thus contribute to the conservation of cetacean populations and the viability of fishing activities in affected areas. They also have wider implications since the management approaches discussed may also be applied in similar fisheries elsewhere. The main objectives, research methodologies, results and conclusions of the present work are summarized in Table 6.1.

Table 6.1. Dissertation synthesis: fisheries and cetacean species covered, aims & objectives, research methods, and main results & conclusions

	Chapter 2	**Chapter 3**	**Chapter 4**	**Chapter 5**
Title	Cetacean occurrence and habitat preferences in Iberian Atlantic waters: results from a co-operative research involving local stakeholders.	Cetacean-fishery interactions in Galicia (NW Spain): results and management implications of a face-to-face interview survey with local fishers	The effect of acoustic deterrent devices "pingers" on two commercially important shoaling pelagic fish species in Iberian Atlantic waters	Experimental fishing with an "umbrella-and-stones" system to reduce interactions of sperm whales and seabirds with bottom-set longlines for Patagonian toothfish (*D. eleginoides*) in the South West Atlantic
Fishery	Galician & Portuguese fleet in national waters (small-scale/artisanal & large-scale fisheries) Multiple gears	Galician fleet in national waters (small-scale/artisanal & large-scale fisheries) Multiple gears	Study results mainly relevant for: Purse seine and coastal gillnet fisheries targeting shoaling pelagic fish species	Spanish large-scale longline fishery in international SW Atlantic waters Experimental bottom-set longline with "umbrella & stones" system
Cetacean species	Common dolphin (*D. delphis*) Bottlenose dolphin (*T. truncatus*) Harbour porpoise (*P. phocoena*) Long-finned pilot whale (*G. melas*) Striped dolphin (*S. coeruleoalba*) Killer whale (*O. orca*) Sperm whale (*P. macrocephalus*) Baleen whales	Multiple species, but mostly: Common dolphin (*D. delphis*) Bottlenose dolphin (*T. truncatus*)	Multiple species, but mostly: Common dolphin (*D. delphis*) Bottlenose dolphin (*T. truncatus*)	Sperm whale (*P. macrocephalus*)

	Chapter 2 cont.	**Chapter 3 cont.**	**Chapter 4 cont.**	**Chapter 5 cont.**
Aims and objectives	• assess cetacean occurrence, habitat preferences and the potential for cetacean-fishery interactions in the study area • evaluate the performance and reliability of different opportunistic survey methods	• assesses types of cetacean-fishery interactions • determine scale of interactions (frequency of occurrence; bycatch rates; catch loss, gear damage and associated economic loss) • identify specific problematic interactions ("hotspots", i.e. fisheries/cetacean species) • evaluate different mitigation methods	• analyse the behavioural and physiological stress response of sardine (*S. pilchardus*) and horse mackerel (*T. trachurus*) to pinger sounds • assess possible negative effects of pinger use on catch rates of sardine and horse mackerel • discuss the feasibility of pinger use in local fisheries directed at these species	• determine the extent of sperm whale depredation on catch and cetacean (and sea bird) bycatch • assess the relationship between sperm whale sightings, occurrence of depredation, catch rates and environmental & fishery data • test the efficiency and feasibility of the "umbrella & stones" system to reduce interactions
Survey method	• Co-operative research approach with active participation of stakeholders (fishers, fisheries observers, regional fisheries authorities, scientists) • Combination of different opportunistic sampling methods (interview survey, on-board observations)	• Face-to-face interviews with fishers in fishing harbours	Tank experiments, assessing the response of fish to the sounds of three different pinger models: • behavioural observations with underwater camera to analyse fish swimming behaviour • blood analysis to measure fish stress level by means of plasma cortisol concentration	• on-board observations by scientific observer (dedicated) and skipper(opportunistic)
Data analysis	Generalized Linear Modelling (GLM) GIS mapping	Generalized Linear Modelling (GLM)	Gaussian distribution: Generalized Least Square (GLS) & Linear Mixed Effects (LME) Models Poisson distribution: Generalized Additive (Mixed) Models (GAM/GAMM)	Generalized Additive Models (GAM)

	Chapter 2 cont.	Chapter 3 cont.	Chapter 4 cont.	Chapter 5 cont.
Main results	• Common and bottlenose dolphin were the species most frequently sighted • Common dolphin was frequently observed in the vicinity of trawls and polyvalent vessels in waters >50 m depth, but also close to purse seines in coastal waters • Bottlenose dolphins were mainly sighted close to coastal artisanal gears, particularly inside the South Galician rías, but also from vessels operating further offshore in Portuguese waters • Harbour porpoise were seen over the whole continental shelf, often in the vicinity of beach seines • Long-finned pilot whale & striped dolphin sightings were mostly observed from vessels fishing offshore(trawlers, longliners and polyvalent boats) • For some cetacean species, sightings frequency was significantly influenced by the type of survey method	• Cetacean-fishery interactions are frequent in Galicia, although damage to catch and fishing gear by cetaceans was mostly reported as small • Nevertheless, substantial economic loss can result from bottlenose dolphins damaging coastal gillnets and from common dolphins scattering fish in purse seine fisheries • Damage to catch and gear is also caused by non-cetaceans • Cetacean bycatch mortality, mainly of common and bottlenose dolphins, was reported to be highest for trawls and set gillnets, respectively	• The sounds of two of the three pinger models tested caused subtle, but significant changes in schooling behaviour of both fish species and in plasma cortisol concentrations of sardine	• Sperm whales were sighted during one third of the hauls, always during gear retrieval, and their presence was positively related to fish damage • The frequency of sperm whale sightings was also positively related to the time of the day (highest during the day), moon phase (waxing moon) and water temperature (≈11°C) • The overall depredation rate was low, but catch per unit effort (CPUE) decreased when there were more sperm whales around the vessel • The "umbrella-and-stones" system completely prevented cetacean/seabird bycatch and appeared to restrict depredation by sperm whales, but significantly reduced catch rates

	Chapter 2 cont.	Chapter 3 cont.	Chapter 4 cont.	Chapter 5 cont.
Main conclusions	• Cetacean occurrence patterns are primarily linked to the distribution of their prey • Common and bottlenose dolphin have the highest probability of being involved in interactions with fisheries, the first most likely with offshore fisheries and purse seiners, and the latter with coastal fisheries • All survey methodologies were complementary and performed well, delivering results consistent with previous scientific surveys, although sighting frequency of some cetacean species was biased by survey method • Although opportunistic sampling has certain restrictions concerning reliability, it can cover several habitats at comparatively low cost and make use of local ecological knowledge that can yield complementary information required for cetacean conservation	• Case-specific management strategies are required to reduce interactions with cetaceans as conflicts are restricted to certain fisheries • Fishers should be actively involved in the development and implementation of mitigation tools • In set gillnets and purse seines, the use of pingers may prevent cetaceans from approaching and getting trapped in the nets • For trawl fisheries, where bycatch appears to be particularly high at night in water depths of 200 – 350 m , time/area closures may be implemented to reduce bycatch • Although interview data may be biased due to fishers' opinions, and therefore should be interpreted with care, the survey method allowed for the coverage of multiple sites / fisheries within a reasonable time-frame and delivered results consistent with previous studies	• The pinger models trialled did not cause a clear aversive behavioural reaction or physiological stress response in fish and are therefore not likely to reduce catch rates of sardine and horse mackerel • The subtle behavioural and physiological changes observed in fish exposed to pingers are more likely to be caused by biological and environmental factors than by the pinger sounds • Long-term field trials should be conducted in the study area with the active co-operation of affected fisheries, to assess pinger efficiency on target cetaceans, the magnitude of possible side effects on non-target cetaceans and catch rates of fisheries target species, as well as the willingness of local fishers to accept this mitigation tool	• Sperm whales are probably attracted to the longline by sound cues during gear-hauling, taking fish off the line close to the surface • Although overall depredation rate was low, catch loss is assumed to be underestimated since sperm whales were suspected of also taking fish without leaving visual evidence • Sperm whales may actually have a negative impact on catch rates, particularly if they attack the longlines in large groups • The "umbrella & stones" system was highly effective in preventing cetacean/seabird bycatch • Given the appropriate design, umbrellas might be useful in preventing sperm whales from taking large quantities of catch although reduced catch rates, may undermine this benefit • Fishers should become active participants in the development of new longline designs

6.1 POTENTIAL FOR CETACEAN-FISHERY INTERACTIONS: OVERLAP BETWEEN CETACEAN PREY AND FISHERIES TARGET SPECIES

A detailed knowledge of cetacean occurrence patterns in relation to environmental variables and fishing activities can help to identify hotspots for conflicts between cetaceans and fisheries (Torres *et al*., 2003), and therefore represents a first important step in the assessment of cetacean-fishery interactions and their management (MacLeod *et al*., 2008). Cetacean distribution and habitat preference may be driven by several environmental factors, although the primary factor is probably the distribution and local concentration of their prey, which in turn is largely influenced by abiotic variables, such as water temperature, salinity, water depth, productivity and characteristics of the seafloor (Torres *et al*., 2008).

Intensive fisheries potentially reduce the availability of cetacean prey, while cetaceans, in turn, may have a negative effect on fisheries through the consumption of fisheries target species (Reeves *et al*, 2001). The decline of the Mediterranean common dolphin population, for instance, has probably been caused by prey depletion resulting from overfishing (Bearzi *et al*., 2008). If cetaceans and fisheries compete for the same resource, cetacean foraging efforts and fishing activities may be concentrated in the same area and operational interactions may arise, especially if shared resources are scarce (Northridge, 1984).

The results of this work indicate that cetaceans occur in marine areas also exploited by fisheries in Iberian Atlantic waters. Depending on the type of fishery, i.e. type of gear and target species, different cetacean species are observed in the vicinity of the fishing vessels.

Common dolphins, for instance, are frequently seen where trawls and purse seines operate. These fisheries mainly target blue whiting and shoaling pelagic fish such as horse mackerel, European sardine and European anchovy, all of which are important prey species of common dolphins in Iberian Atlantic waters (Silva, 1999; Pusineri *et al*., 2007; Méndez Fernández *et al*., 2012; Santos *et al*., 2013). The estimated consumption of horse mackerels (*Trachurus* spp) by common dolphins was calculated to be around 10% of the Portuguese and Spanish landings for *Trachurus trachurus* in Iberian Atlantic waters (Santos *et al*., accepted). Note that it was not possible to differentiate the otoliths and bones of the genus *Trachurus* recovered from the stomachs into one of the three species present in the area. Sardine consumption by common dolphins is more important in Portugal than in Galician waters while estimated hake and blue whiting consumed by common dolphins represent also an important figure when compared with fisheries landings (in 2002: 16% and 42% of fisheries landings, respectively) (Santos *et al*., accepted). In the Bay of Biscay, common dolphin consumption of small pelagic fish is of the same order of magnitude than fisheries (Pusineri *et al*., 2004; Lassalle *et al*., 2012).

Bottlenose dolphins feed on a large variety of prey in Iberian Atlantic waters, mainly on blue whiting and European hake, but also on silvery pout, mullet, pouting, European conger, horse mackerel, European sardine and cephalopods (Santos *et al*., 2007; Sollmann, 2011; Santos *et al*., accepted), and therefore share resources with multiple fisheries, particularly the ones operating in coastal waters. Santos *et al*. (2007) suggested that bottlenose dolphins are potentially competing with fisheries for blue whiting in Galicia, because similar size classes of fish are taken by fisheries and cetaceans in the same area. Direct and indirect competition of bottlenose dolphins with fisheries (in particular for European hake) was observed in the Bay of Biscay (Pusineri *et al*., 2004; Lassalle *et al*., 2012).

Harbour porpoise feed on shallow-water (e.g. pouting) and deep-water (e.g. blue whiting, horse mackerel and garfish) species (Spitz *et al*., 2006a; Read *et al*., 2012) and therefore potentially compete with several types of fisheries in Iberian Atlantic waters. Due to the small population size in Iberian Atlantic waters, the biomass consumed by harbour porpoise was estimated to be low (Pusineri *et al*., 2004; Santos *et al*., accepted), although fisheries, in turn, are suggested to cause significant bycatch mortality (Lassalle *et al*., 2012), particularly in coastal fishing gear such as beach seines (Ferreira, 2007).

Long-finned pilot whale and striped dolphin mainly feed on non-commercial cephalopods and fish (Santos *et al*., 1996; Spitz *et al*., 2006b, 2011; Sollmann, 2011; Méndez Fernández *et al*., 2012; Santos *et al*. In Press b; Santos *et al*., accepted), although some commercial species are also consumed (e.g. common octopus by long-finned pilot whales and blue whiting and horse mackerels by striped dolphins) (Santos *et al*., In Press b; Santos *et al*., accepted).

Summarising the above described findings, common dolphins, bottlenose dolphins and harbour porpoises, due to the significant dietary overlap with fisheries target species and, in the case of the first two also due to their high abundance, have the highest potential to be involved in operational interactions with fisheries in Iberian Atlantic waters, while pilot whales and striped dolphins, due to their oceanic habitat are less likely to interact frequently with fisheries.

6.2 TYPES, EXTENT AND POTENTIAL COSTS/BENEFITS OF CETACEAN-FISHERY INTERACTIONS IN IBERIAN AND SW ATLANTIC WATERS

The results of this work show that cetaceans interact with several fisheries in Iberian and South West Atlantic waters, although the type, frequency, extent and positive/negative effects of the interaction varies with the type of fishery and cetacean species involved.

6.2.1 POSITIVE INTERACTIONS

Positive interactions, e.g. fishers using cetacean occurrence as a cue for the presence of fish schools, were only observed in purse seine fisheries. Since the dolphins are easier to sight at a distance than fish and therefore make the fish swimming underneath them easier to detect and follow, the chance of fishing success increases. Similar mechanisms are described for the Eastern Tropical Pacific tuna fishery, where dolphins are even actively chased to catch the tuna. This type of "co-operative fishing" can help to increase catch rates, but it has to be kept in mind that accidental mortality of cetaceans in the purse seines may be substantial for this fishing method, especially if no bycatch reduction measures (see **Section 6.4.1**) are applied. In addition, the presence of cetaceans around purse seines may scatter fish before the net is pursed and therefore also have a negative effect on catch rates, which will be discussed below. It is also probable that cetaceans use the presence of fishing boats (e.g. detected due to the noise made by the boat or by towed gear) or fishing gear (e.g. fixed nets, lines) as a means to detect feeding opportunities and/or to facilitate the capture of prey: the occurrence of depredation shows that cetaceans can benefit from interactions with fishing operations. To the extent that such interactions are detectable, they probably also have negative consequences for fisheries. If cetaceans use the presence of fishing boats or gear to find prey, but do not actually remove fish from the gear or cause fish to move away, the reaction may be positive from the perspective of the cetaceans, neutral from a fisher’s viewpoint – and virtually impossible to detect or quantify.

6.2.2 NEGATIVE INTERACTIONS

Negative interactions, in contrast, affected most fisheries in the study area (all except artisanal longline and trap fisheries) and were observed more frequently than positive interactions (although, as above, positive interactions may be inherently more difficult to detect). Fishers operating in Iberian Atlantic waters reported that cetaceans, mainly common and bottlenose dolphins, regularly damage fishing equipment (by getting entangled or during the attempt to remove fish from the fishing gears), reduce the quantity or value of the catch (by scattering fish pre-capture or by removing or damaging fish post-capture) and/or get incidentally caught in their fishing gear. In large-scale bottom-set longline fisheries in Patagonian waters, sperm whale depredation on catch was the main cetacean-related problem, while gear damage and cetacean bycatch were of minor concern (although bycatch of seabirds may be significant). In all fisheries surveyed, negative interactions with cetaceans were always reported to imply loss of time and money, for instance through slowing down fishing operations, the need to navigate to alternative "cetacean-free" fishing areas, material and labour expenses for net repair, and the loss of marketable fish through ineffective fishing gear and direct depredation. Views about possible negative impacts of bycatch mortality on cetacean populations were, however, rarely expressed by fishers.

6.2.3 ECONOMIC LOSS FOR FISHERIES

Although interactions with cetaceans were frequently reported by Galician fishers, economic loss associated to catch loss and gear damage was mostly described as negligible. For some fisheries, however, profits may be significantly reduced, as in the case of artisanal gillnet (set gillnets and driftnets) and purse seine fisheries in Iberian Atlantic waters and large-scale bottom-set longline fisheries in the South West Atlantic.

For artisanal gillnet fisheries, net damage was of greater economic concern than consumption of catch by cetaceans. Several fishers reported that cost arising from damaged fishing gear can account for 10% and more of their gross income. This number is comparable to the value calculated by Bearzi *et al*. (2011), who estimated the mean economic loss of artisanal trammel net fishers in the Mediterranean as € 2561 per year. A slightly lower estimate of 5.3% of the total catch value was given by Brotons *et al*. (2008a) for trammel net fisheries in Balearic waters.

The proportion of catch consumed by cetaceans and associated economic loss was mostly classified as low by fishers operating artisanal gillnets. This may be due to the fact that dolphins either only depredate on nets when catch is high, i.e. in areas with high fish abundance, or drive the fish actively into the nets thereby increasing catch, as hypothesized by Silva *et al*. (2002). Taking into account the quantity of catch additionally consumed by crustaceans, cephalopods and predatory fish, economic loss may, however, become significant.

In purse seine fisheries the whole catch of a haul or fishing trip may be lost if cetaceans interfere during the fishing operation. This worst case scenario, however, was reported to be a sporadic rather than a regular event (as also observed by Wise at al. (2007) in Portuguese purse seine fisheries), and when allocating sporadic economic losses over the course of a whole year, profits are probably not significantly impacted. In seasons with increased demand and thus higher market prices of shoaling pelagic fish (e.g. European sardine in summer), however, cetacean-fishery interactions may become more frequent due to intensified fishing activities, and income may temporarily be substantially reduced.

In large-scale bottom-set longline fisheries in the South West Atlantic, sperm whales damaged a comparatively small amount of Patagonian toothfish (< 1% of total catch), although, due to the high market value of the fish, even a slight catch reduction may imply noticeable economic losses. Moreover, there were some indications that a considerable amount of fish may be consumed by the whales without leaving visual evidence on the hooks, i.e. it is likely that some depredation goes unrecorded. If many sperm whales are present in the fishing zone, the captain may decide to relocate the fishing operation to an alternative, distant area, in order to avoid interactions with sperm whales, which implies a loss of fishing time and additional expenses for petrol. These extra costs, together with the loss of marketable fish, can potentially have a significant negative impact on income. Tixier *et al*. (2010) estimated the cost of killer whale and sperm whale depredation on toothfish catch around the Crozet Islands (South Indian Ocean) as € 140 000 per boat and fishing season.

In contrast to large-scale longlines, artisanal longlines in Iberian Atlantic waters were apparently not affected by cetacean depredation, although cetaceans (especially oceanic species) were frequently observed in their vicinity. This may probably be due to the fact that the main target species of this gear (e.g. European conger, black scabbardfish) are not an important prey of cetaceans in the area. Off the Azores archipelago, depredation by bottlenose dolphins on demersal fish on hook and line gear was reported by Prieto *et al*. (2005), Catarino (2006) and Silva *et al*. (2011), although no significant reduction of catch rates was observed in these studies.

Traps and pots are also not likely to be affected by depredation and gear damage by cetaceans, since their design and the materials used (metal frames and wires) usually restrict the cetaceans' access to the catch trapped in the gear. Smaller predators, such as cephalopods, sea stars and crustaceans, however, were frequently reported to enter the traps and feed on catch.

6.2.4 CETACEAN BYCATCH

The cetacean mortality caused by fisheries is thought to be high in Galician and Portuguese fisheries. López and Martínez Cedeira (2010) reported that more than half of the stranded common dolphins examined in Galicia between 2000-2009 exhibited signs of having died as a result of bycatch (considering only animals in a sufficiently good state of preservation to be able to determine the cause of death). In Portugal, the studies of Sequeira (1996) and Silva and Sequeira (2003) suggested that around one-half of stranded cetaceans may have died in fishing gear.

As several other studies in Iberian Atlantic waters (Sequeira, 1996; Aguilar, 1997; López *et al*., 2003; Silva and Sequeira, 2003; Fernández Contreras *et al*., 2010; López and Martínez Cedeira, 2010), the results of the present work indicate that cetacean mortality is highest in trawls and set gillnets. The mechanisms of incidental entanglement in fishing gear are generally not very well understood. However, there are several hypotheses. Cetaceans frequently associate with trawls, particularly pelagic trawls, probably because the trawling nets concentrate food resources and make them easily exploitable for the cetaceans (Fertl and Leatherwood, 1997). While feeding on fish inside or around the trawl nets, the animals may become entangled and drown (Read, 1996). Nevertheless, not every cetacean-trawl interactions results in bycatch. Underwater video footage analysed by Mackay (2011) showed that bottlenose dolphins seem to be aware of the trawl nets, actively touching the net from inside and outside, and are in principle able leave the net through the trawl mouth again after feeding. The dolphins were observed to back down in the trawl net towards the codend (with the beak towards the vessel) as far as possible to areas where they were still able to manoeuvre, using the surrounding net as a barrier to herd the incoming fish together to feed on them. Jaiteh (2009) suggested that bycatch in trawls is more likely to occur when young, unexperienced animals enter the net or when the net is fishing incorrectly, e.g. when it collapses or becomes twisted. Incidental entanglement in gillnets is thought to occur when cetaceans are unaware of nets, for instance if they do not detect gillnets at sufficient distance to avoid them or when they fail to echolocate during navigation. It is also possible that the dolphins can detect the nets, but simply do not perceive them as a barrier/danger. While feeding around gillnets, they may be distracted by other stimuli in the vicinity of the nets (Read, 1996; Read *et al*., 2003). In field trials, harbour porpoise and bottlenose dolphins were found to produce faster echolocation click trains in the presence than in the absence of gillnets, which may indicate that cetaceans forage or investigate the area around the nets (Lauriano and Bruno, 2007; Mackay, 2011). Mackay (2011) hypothesized, that entanglement may occur because porpoises might not concentrate on the closeness of the net while they pursue their prey around the gear.

Read *et al*. (2006) pointed out that the high fishing intensity with artisanal gears in some countries is likely to have a severe impact on regional populations of small cetaceans. High bycatch mortality in small-scale fisheries was also reported by D'Agrosa *et al*. (2000) and Amir *et al*. (2002). This is probably also the case in Galicia, where small-scale fisheries make up the majority of the fleet. Although bycatch rates reported by artisanal fishers may appear low at first glance, it has to be considered that the cumulative negative impact of small-scale net fisheries on cetaceans, in particular bottlenose dolphins, is likely to be high. Our estimates indicate that the bycatch mortality of bottlenose dolphins (mostly in artisanal gillnets) and common dolphins (mostly in large-scale trawls) are probably unsustainable in Galicia, which is in agreement with the results of López and Martínez Cedeira (2010). There is cause for concern especially for the genetically distinct resident bottlenose dolphin population in the South Galician rías that may be impacted most severely by bycatch mortality, particularly if the dolphins are additionally exposed to other threatening human activities such as overfishing, habitat degradation, pollution and boat traffic (Fernández *et al*., 2011b).

In Portugal, where beach seines are commonly used, bycatch of harbour porpoise may also reach unsustainable levels (Silva and Sequeira, 2003; Ferreira, 2007).

Although cetacean bycatch is frequently occurring in Galician purse seines fisheries, the mortality rate reported by fishers is very low, since cetaceans are usually able to leave the purse seine unaided or, in case they fail, being helped by fishers through lowering the cork line. The same was reported for Portuguese purse seine fisheries (Wise *et al*., 2007). Nevertheless, there are some indications that in Portuguese purse seine fisheries it is a common practice to drag the encircled dolphins out of the pursed net by towing a rope around their tail. Recent necropsy data indicate that a large number of number of stranded animals show bone damage and injuries probably caused by this release practice (J. Vingada, Pers. Com.). Therefore, the post-release mortality of cetaceans caught in purse seines may actually be high.

Cetacean bycatch on longlines may occur when the animal becomes caught on a hook when attempting to remove the catch, although this is usually an occasional event (Read, 2005; Secchi *et al*., 2005).

6.3 SUITABILITY OF DIFFERENT METHODOLOGIES TO ASSESS CETACEAN-FISHERY INTERACTIONS

Cetacean-fishery interactions usually affect a large variety of fisheries, operating over a wide geographic area. Some gears are only used seasonally and/or in certain fishing areas. In addition, due to cetacean habitat preferences, different cetacean species and consequently types of interactions can be expected to occur in coastal and offshore areas. Therefore, in order to allow for a holistic assessment of cetacean-fishery interactions that also accounts for spatio-temporal variability, broad-scale sampling methods need to be applied.

Systematic long-term surveys with dedicated observers on-board fishing vessels are probably the most reliable method to study fisheries interactions with cetaceans, but costs and logistical effort of such surveys are usually very high, even if only a minimum representative proportion of the fleet and fishing areas are sampled. Moreover, space on-board fishing vessels is restricted and fishers may not be able and/or refuse to regularly carry observers. If specific cases or fine-scale mechanisms of cetacean-fishery interactions need to be analysed over a short time period, dedicated on-board observations may, however, be financially and logistically feasible.

Interview surveys, as well as opportunistic observations from fishing vessels are cost-effective alternatives to dedicated observer surveys. Both alternative survey methods allow for the coverage of different types of fisheries on a wide geographic and temporal scale, although data reliability tends to be lower than for dedicated observations.

Apart from the advantages described above, both interview surveys and opportunistic on-board observations allow for "co-operative research", i.e. the active collaboration of different stakeholders (e.g. fishers, fisheries observers, scientists, etc.) in scientific research and management (Johnson and van Densen, 2007). Fishers and fisheries observers spend a considerable amount of time at sea and therefore have long-term local ecological knowledge (LEK), for instance about the distribution of marine mammals and fish, their behaviour and temporal or food-related variations in their movement patterns. In addition, they have an extensive practical knowledge of fishing gear and the factors that influence fishing success (Johannes *et al*., 2000). Therefore, the expertise and information provided by these stakeholders, can be a valuable tool to complement "western scientific approaches" to research and resource management, especially if scientific data are difficult to obtain (Johannes *et al*., 2000; Gilchrist *et al*., 2005). Co-operative research can also significantly reduce monetary costs of data collection, since the costs for hiring fisheries observers and the use of fishing vessels can be shared between institutions, e.g. between research institutes and the local government that employs the observers for fishery control programmes. Nevertheless, if LEK is used in scientific studies, it is important to carefully compare the information derived from LEK with scientific results in order to evaluate the reliability and the constraints of both approaches (Huntington *et al*., 2004; Gilchrist *et al*., 2005).

6.3.1 INTERVIEW SURVEYS

Interviews with fishers have been used to assess cetacean-fishery interactions by several authors in recent years (Amir *et al*., 2002; López *et al*., 2003; Díaz López, 2006; Zollet and Read, 2006; Wise *et al*., 2007; Jaaman *et al*.,2009; Lauriano *et al.*, 2009; Moore *et al.*, 2010; Bearzi *et al.*, 2011). Especially for small-scale fisheries, where vessel-based observations are generally not feasible due to limited space on-board, interview surveys provide a useful low cost technique to identify fisheries with high bycatch rates (Moore *et al.*, 2010). Read (2008) pointed out that, although the impact of small-scale fisheries on non-target species can be high (which is consistent with our findings), there is a large knowledge gap concerning bycatch rates in these fisheries, which urgently needs to be addressed. In contrast to on-board observations that collect information on specific interaction events, interview surveys can be designed to capture fishers' general experiences and long-term trends in cetacean-fishery interactions. Information collected in interview surveys is largely qualitative. Moreover, if the questionnaire also includes quantitative questions, such as the estimation of catch/money loss through interactions or bycatch rates, fishers tend to indicate ranges of numbers rather than single values. This information can, however, be grouped into categories and assigned to different levels (e.g. low, moderate and high) in subsequent data analysis. Interview surveys can therefore give valuable insights into the scale of cetacean-fishery interactions, although exact numerical estimates are difficult to derive from this method.

Interview data may be potentially biased by the opinions of fishers (especially for sensitive information, they may not choose to tell the truth), low expertise of the respondent, unsystematic sampling effort, and (in the case of face-to-face interviews) by the unintended influence on the interviewee through the interviewer. Therefore results should be interpreted with care (Czaja and Blair, 2005; White *et al*., 2005; Moore *et al*., 2010).

To minimize bias, a questionnaire format containing mainly closed-ended questions was selected in order to standardize and maximize the accuracy of information obtained and to reduce the uncertainty in questions and answers for both interviewer and interviewee (Moore *et al*., 2010). The inclusion of some open-ended questions gave the interviewees the opportunity to state their personal opinions and suggestions, which often yielded additional, unanticipated insights into the behaviour and perceptions of fishers. If fishers were not sure about their answer, they always had the option to choose "don't know". In order to make sure cetacean species were correctly identified by interviewees, the fishers were asked to point to the species seen and indicate the name in a catalogue of photographs of cetaceans, not labelled with species name. Since (at least in some countries) fishers confronted with cetacean bycatch are likely to under-report the number of bycaught animals, because they are afraid of possible sanctions (Hamer *et al*., 2008), all interviews were kept anonymous and we assured interviewees that all personal data would be treated as confidential. If available, interviews were always conducted with the skipper of the vessel, who was assumed to have the highest level of expertise within the crew.

Extrapolating the information obtained on cetacean-fishery interactions to an entire fishing fleet requires that data are collected systematically from a representative sample of the fleet. This was achieved by applying a stratified sampling procedure, based on type of fishing gear: selecting harbours according to their representativeness for a certain fishing gear, sampling boats opportunistically within the selected harbours (Lauriano *et al*., 2009) and using post-stratification weights in order to exactly adjust the relative proportions of each type of fishery in the sample to their actual proportions in the surveyed fleet.

To avoid the possibility that interviewees chose the answer they thought the interviewer would want to hear, the questions were read to the fishers exactly as written on the questionnaire speaking in a neutral tone, i.e. without any positive or negative accentuation. In addition, only two interviewers were engaged in the study and they were well-trained beforehand. When there were only few fishers present in the harbour, interviews were taken in turns by the interviewers, so that they could observe each other to make sure that interviews were conducted consistently.

The costs of face-to-face interview surveys, e.g. for travelling and accommodation, can be kept moderate, as long as fishing harbours are not too far from each other and reachable within a few hours. Nevertheless, the expenditure of time spent in the harbours may be quite high due to the nature of the fishers' work. Even when one has a rough estimate of the time the fishers normally land the catch, many factors such as bad weather can often mean that fishing trips may last several hours longer than anticipated, resulting in long waits in harbours for the interviewers.

6.3.2 OPPORTUNISTIC ON-BOARD OBSERVATIONS

Although opportunistic data are suboptimal and have inherent procedural limitations in comparison to dedicated surveys, the active involvement of skippers and fisheries observers in data collection allows for the observation of a large number of fishing trips (covering several gears and fishing areas) and can therefore provide information that would otherwise be unavailable (Moura *et al*., 2012).

On-board observations offer the possibility to identify the exact locations where cetaceans are seen and interactions with fisheries are observed. Moreover, detailed information about cetacean-fishery interactions, such as the type of cetaceans involved (adults, juveniles, mothers with calves), their fine-scale behaviour and an accurate description of damage to catch and gear, can be obtained.

The main problem with opportunistic on-board observations is that sampling is not spatially or temporally randomized and may be restricted to particular routes, certain time of the day or phase of tide (Isojunno *et al*., 2012). If data on total fishing effort in a certain area are not available to scientists (which is also the case in the present work), sampling effort cannot be appropriately quantified. In addition, observations made exclusively from fishing vessel are obviously restricted to areas with fishing activities (and transit routes between ports and fishing areas) and can therefore not provide insights into cetacean occurrence patterns in (most) non-fishing areas. Although these limitations are apparent, an adequate spatial and temporal coverage can be approached by surveying coastal and offshore fisheries over a reasonable time period, e.g. over 2-3 years as in the present study. This allows for the coverage of several habitat types as well as for the incorporation of seasonal or interannual variability in the occurrence of cetaceans and their interactions with fisheries.

The reliability of information collected by fishers and fisheries observers is another frequent point of criticism. Some skippers/fisheries observers involved may have a low level of expertise in the identification of cetaceans. Moreover, they may be busy with other tasks on-board and not have enough time to record information about cetacean sightings or interactions. Therefore correct identification of cetaceans is not always guaranteed and cetacean presence records may be poor. In order to tackle these problems, fisheries observers and skippers need to be thoroughly briefed about the correct observation methodology and identification of cetaceans. This can be achieved by providing them with training and illustrative material. They should also be provided with a short, simple, standardized questionnaire that facilitates fast and easy data collection. As for interview surveys, data collected by skippers should be kept anonymous and treated as confidential, in order to avoid the possibility that cetacean bycatch rates are under-reported.

6.4 IMPLICATIONS FOR MANAGEMENT AND MONITORING OF CETACEAN-FISHERY INTERACTIONS

6.4.1 MANAGEMENT OF CETACEAN-FISHERY INTERACTIONS

Methods to reduce cetacean-fishery interactions include changes in fishing practice as well as technical solutions (e.g. modification of fishing gear and use of acoustic or physical mitigation devices). Depending on the fishery in question, different approaches may be applied.

Set gillnet fisheries face several cetacean-related problems, including high rates of cetacean bycatch, as well as cetacean depredation and gear damage. Net modifications, such as the addition of heavy metal (e.g. barium sulphate) to the gillnet twine, make fishing nets more obvious to odontocete sonar and can therefore help to reduce cetacean bycatch. However, this only works if cetaceans make use of their sonar when they encounter the nets (Dawson, 1994). Compared to regular nylon mesh gillnets, the cost of barium sulphate modified nets is comparable. In addition, barium sulphate modified nets are stiffer and have a 10-15% longer lifespan than conventional nylon nets. Increased stiffness may, however, have a negative impact on gear handling and catch rates (Dawson, 1994; Larsen *et al*., 2002; Trippel *et al*., 2008). Apart from these disadvantages, there also exists the possibility that cetacean depredation on catch increases if nets are easier to detect. Therefore, the use of acoustically reflective nets would only tackle one part of the problem and, in the worst case scenario, augment the negative consequences arising for fishers.

Acoustic deterrent devices (pingers) are designed to alert the cetaceans to the presence of fishing gear. Pingers have been demonstrated to reduce operational interactions with several cetacean species, including common dolphin (e.g. Barlow and Cameron, 2003; Carretta and Barlow, 2011), bottlenose dolphin (e.g. Leeney *et al*., 2007; Brotons *et al*., 2008b) and harbour porpoise (Culik *et al*., 2001; Carlström *et al*., 2009) and may therefore also help to mitigate bycatch of and depredation by these species in Spanish and Portuguese set net fisheries. The displacement effect of pingers is thought to be higher for "shy" cetacean species, such as the harbour porpoise, while for the more "inquisitive" bottlenose dolphin it seems to be less pronounced (Cox *et al*., 2003), although this also largely depends on the technical specifications (e.g. source level, frequency range) of the pinger. These specifications need to be adapted to the hearing ranges of the cetacean species they are supposed to deter (Kastelein *et al*., 2006). The efficiency of pingers may, however, decrease over time if cetaceans habituate and/or become sensitized to the pinger sounds which would lead to a reduced reaction or, in the latter case, even an active attraction (so-called "dinner bell effect") to the pingers (Richardson *et al*., 1995; Cox *et al*., 2003). For common dolphin and harbour porpoise no such effect was detected in studies conducted over several years (Palka *et al*., 2008; Carretta and Barlow, 2011), but for bottlenose dolphin, a species with advanced learning abilities that is quick at discovering new foraging opportunities (Whitehead *et al*., 2004), habituation/sensitization may occur, although this has not been demonstrated in long-term studies yet. Periodical changes in the frequency spectrum of the pingers and the use of responsive pingers (which only emit sounds when activated by cetacean clicks) may reduce the probability of habituation (Leeney *et al*., 2007; Gazo *et al*., 2008).

Pingers can also cause the exclusion of some cetacean species from parts of their habitats. Especially if several species of cetaceans co-exist in the same area, pingers applied to deter one cetacean species (e.g. bottlenose dolphins) may be too loud for other cetacean species (e.g. harbour porpoise) and exclude them from their habitat or even cause hearing damage, if the source level is excessively high (Culik *et al*., 2001; Carlström *et al*., 2009). This is especially a problem in coastal areas where both species are most frequently observed and can only be solved by choosing a source level that is tolerable for harbour porpoise (and other cetacean species with high hearing sensitivity), but sufficiently high to cause aversive behaviour in less sensitive species, such as the bottlenose dolphin.

Apart from their side-effects on cetaceans, pinger can also have negative effects on fisheries target species. The absence of a negative impact on fishing success is, however, a significant element in ensuring fishers' acceptance of pingers (Gazo *et al*., 2008). Although most studies assessing this issue did not detect a significant negative effect of pinger sounds on catch rates, some fish species (e.g. seabass, herring, mullet) seem to be able to hear the pinger sounds (Kastelein *et al*., 2007). Spanish and Portuguese set net fisheries target a large variety of fish and a potential negative impact of pingers on catch rates cannot be excluded as long as the effects of pingers are not assessed for all fisheries target species.

Pingers can be relatively easily attached to nets, although operational problems, such as time taken in attachment and tangling of the gear, have been reported. In addition, incorrect spacing of pingers and malfunction (e.g. battery failure) may reduce the pinger efficiency (Dawson *et al.*, 2013).

Last but not least, pingers are still relatively expensive and may therefore not be affordable for small – scale fishers. Governmental subsidies may be needed to solve this problem. In addition or alternatively to subsidies, the promotion and implementation of eco-certification of dolphin-safe fishing methods may help fishers to obtain higher prices for their products. These additional profits could be used to offset the expenses for pingers. Environmental education activities, such as stakeholder workshops, as well as the distribution and public dissemination of information about cetacean bycatch and cetacean-friendly fishing practice, may increase the motivation of fishers to use pingers and the willingness of the consumers to pay higher prices for ecologically sound fishery products.

In **purse seine fisheries** where cetaceans (primarily common dolphin) need to be kept away from the gear in order to prevent scattering of fish, pingers may also be a possible solution. To date there is little information on the effectiveness and feasibility of pinger use in this fishery. However, preliminary results of field trials conducted in Portuguese purse seine fisheries indicate that pinger use can substantially reduce dolphin bycatch mortality (Vingada *et al.*, 2011) and pingers have also shown to be efficient in deterring common dolphins from other types of pelagic nets (e.g. driftnets, Barlow and Cameron, 2003; Carretta and Barlow, 2011). In addition, the results of this work suggest that negative effects on catch rates of important purse seine target species, such as European sardine and Atlantic horse mackerel, are not likely. However, the motor noises of the main vessel and the auxiliary boat during the purse seining process may mask the pinger sounds and therefore reduce their audibility for cetaceans in the vicinity of the nets. The survival rates of cetaceans trapped in purse seines may be significantly improved by informing and training fishers about the best practice to avoid bycatch and appropriate methods to release cetaceans from the nets. In the Eastern Tropical Pacific fishery for yellowfin tuna, for instance, cetacean bycatch has been a serious issue (Francis *et al.*, 1992) until regulatory measures were introduced by the Inter-American Tropical Tuna Commission (IATTC) during the 1980s and 1990s. The "back-down" procedure (described in **Section 1.7.1**), in combination with the use of medina panels, i.e. panels of fine mesh attached to the net section of the purse seine farthest away from the vessel, combined with the training of fishers, have dramatically reduced bycatch in this fishery

(Gosliner, 1999; Hall *et al*., 2000). The small mesh size of the medina panel makes dolphin entanglement unlikely and allows the animals to escape over the corkline which is lowered by the backward towing of the purse seine.

In **trawl fisheries** cetacean bycatch also needs to be reduced. Apart from cetacean mortality, entanglement of cetaceans may also twist or rip the nets and consequently reduce catch. In Galician trawl fisheries, for instance, cetacean bycatch was found to be particularly high during night-tows and in water shallower than 300 m (Fernández Contreras *et al*., 2010). Restricting or prohibiting nocturnal trawling activities in these areas might therefore substantially decrease bycatch rates (Morizur *et al*., 1999; López *et al*., 2003; Fernández Contreras *et al*., 2010).

Pingers designed for trawl fisheries have been trialled in trawl fisheries, but common dolphins did not react to the pinger sounds, probably due to the high noise generation during trawling, and bycatch rates could consequently not be reduced (Northridge, 2006; Leeney *et al*., 2007).

Dolphin exclusion devices have been trialled with mixed results (Northridge *et al*., 2003a; Stephenson et al. 2006, Lyle and Willcox 2008), but given the correct design and handling, exclusion grids have the potential to significantly reduce cetacean bycatch in trawl fisheries. In Australian trawl fisheries bycatch of bottlenose dolphins was reduced by 50% through the deployment of exclusion grids (Mackay, 2011). The author suggested that the observed reduction in bycatch can either be assigned to dolphins exiting through the escape hole or to the presence of a physical barrier which increases the chances of a dolphin to escape from the net through the trawl mouth.

In **large-scale bottom-set longline fisheries** small modifications to fishing procedure may be applied to reduce depredation by cetaceans. Sperm whales (and killer whales) usually prey on longlines during gear-hauling when the catch is close to the surface. By minimizing vessel and hauling noises, cetaceans might need longer to detect the locations of the longlines. Using shorter longlines reduces the hauling duration and may give the predators less time to take catch from the line (Moreno *et al*., 2006; Tixier *et al*., 2010).

Pingers may be applied in large-scale longline fisheries (Dyb, 2006), but since pingers usually only have a limited emission range (approximately 200 m), a large amount of pingers would be needed to protect the longline (up to 20 km) along its full length. This would probably be financially unfeasible. In addition, many commercially available pinger models are not functional in deep waters. Acoustic harassment devices (AHDs), which emit sounds at higher source levels than pingers (> 185 dB re 1 mPa @ 1m) (Reeves *et al*., 2001) have been shown to deter sperm whales from longlines, but whales became accustomed to them after a while and stopped avoiding them (Dyb, 2006). A special type of AHD, the "OrcaSaver" (Figure C.3, Appendix C), helped to reduce killer whale depredation on longlines in Antarctic waters (Bates, 2012). This device has a sound emission range of 1000 m and is submerged from the fishing vessel at 10 m below the surface. However, habituation/sensitization is probably also occurring.

Physical depredation mitigation devices (PDMDs) are designed to limit the access of depredating cetaceans to hooked fish in order to reduce damage and removal of catch from the line. In bottom-set longline fisheries this can, for instance, be achieved with net sleeves ("umbrellas"). Moreno *et al*. (2008) reported that the use of the umbrella system can greatly reduce sperm whale depredation.

The umbrellas tested in the present work, however, only reduced sperm whale depredation to a certain extent and, in addition, significantly reduced catch rates. A study by Brown *et al*. (2010) suggests that longlines equipped with umbrellas have less catch than traditional longline systems in areas with high abundance of target species. According to the author this is due the fact that the umbrella system saturates earlier as several hooks are bunched together closely and not every hook will catch a fish even in areas of high localised abundance. In contrast, in areas with lower fish abundance, the umbrella system allows for higher catch than the traditional system, because the grouped hooks provide for a greater quantity of bait in close proximity, probably resulting in a stronger bait plume that attracts target fish from a greater area. Therefore, in "poor" fishing areas, where sperm whale depredation is expected to have a greater negative impact on catch that in "rich" fishing areas, the use of umbrellas may actually be feasible. The net-sleeves can be built by the fishers themselves at relatively low cost. In addition, the amount of bait and the time needed for baiting the hooks is lower for the umbrella system and can therefore reduce material and personnel costs. Similar devices (so-called "socks" and "spiders") (Figure C.4, Appendix C) have been trialled in pelagic longline fisheries, but the devices did not prevent cetacean depredation. Improvements of the current design are in progress (Rabearisoa *et al.*, 2012).

Active decoys are "fake" longlines that are equipped with an acoustic playback device emitting typical fishing vessel noises (motor and hauling noises) and are set at a certain distance to the "real" longline. They are used to distract sperm whales from true fishing activity and can be highly efficient in reducing depredation (Thode *et al.*, 2012).

Bottom-set gillnet, trawl and longline fisheries that primarily target demersal species may also consider to partially or entirely switch to **trap fishing**, since this seems to be the only fishing method unaffected by interactions with cetaceans. Cetacean depredation on Patagonian toothfish, for instance, could be reduced by replacing large-scale bottom-set longlines with traps in the South West Atlantic. Catch rates were, however, significantly lower (Guinet *et al.*, 2010).

An alternative or additional interaction reduction strategy for all fisheries dealt with in this thesis could be the avoidance of fishing areas with high cetacean abundance. The identification of such areas could be facilitated through fleet communication, i.e. the dissemination of real time information on the presence of cetaceans in a certain area between fishing vessels (see Gilman *et al*. 2006b). Additional fuel costs for navigation to alternative fishing areas, as well as potentially decreased catch rates in these areas may, however, reduce or even exceed the benefits of this approach. Moreover, cetaceans may follow the vessels from one area to another. By minimizing operational noises (e.g. of the vessel motor and the fishing equipment) that are thought to attract cetaceans to the vessels, for instance by leaving the area at reduced speed or by hand- or battery-powered gear-hauling, the probability that cetaceans discover fishing gear and/or follow fishing vessels may be reduced (Tregenza, 2001).

In summary, it can be said that there is no single panacea to mitigate cetacean-fishery interactions in all fisheries affected. The types of interactions observed are diverse and require case-specific management strategies. In many cases, a combination of different measures may be more efficient than using only a single mitigation method. Table 6.2 gives a short summary of mitigation strategies and their possible side effects.

The key to the effectiveness of a mitigation method is probably its acceptance by fishers. If fishers are not willing to co-operate, none of the approaches described above are likely to be successful. Participation of fishers in scientific research and management is thought to increase the acceptance of and compliance with measures to reduce cetacean-fishery interactions (Campbell and Cornwell, 2008). Fishers have expertise with fishing gears and their collaboration may allow for the development of better technologies, for instance modified gear design or new technical solutions. Economic incentives can be created by involving fishers into dolphin-watching activities and by promoting the eco-labelling of fish and fishery products such as the Marine Stewardship Council (MSC) that awards certificates to sustainably managed fisheries with minimum impacts on the ecosystem (Salomon *et al*., 2011).

Table 6.2. Suggested strategies to mitigate cetacean-fishery interactions with their respective possible negative side effects/aspects. (Abbreviations: SL – Surface Longline; BL – Bottom-set longline)

	set gillnets			**purse seines**			**trawls**			**longlines**			
	reduction of			reduction of			reduction of			reduction of			
	depredation	gear damage	bycatch	depredation	gear damage	bycatch	depredation	gear damage	bycatch	depredation	gear damage	bycatch	**possible negative effects/aspects**
acoustically reflective nets			x										increased depredation
pingers	x	x	x	x		x				x(SL)			cetacean species-specificity cetacean habituation/sensitization cetacean habitat exclusion cetacean hearing damage reduced catch rates high cost
change fishing area	x	x	x	x		x			x	*x*			increased petrol costs reduced catch rates cetaceans follow vessel
time/area restrictions									x				reduced catch rates
dolphin exclusion devices									x				difficulties in gear handling
reduce vessel and hauling noise	x	x	x	x		x			x	x			time consuming
use short lines										x(BL)			higher logistic effort
physical depredation mitigation devices										x			reduced catch rates
active decoys										x			higher logistic effort
trap fishing	x	x	x						x	x(BL)			reduced catch rates

6.4.2 MONITORING OF CETACEAN-FISHERY INTERACTIONS

Anecdotal or historical records of cetacean occurrence and cetacean-fishery interactions (e.g. Brito *et al*., 2010), as well as cetacean strandings (e.g. López *et al*., 2002; Silva and Sequeira, 2003) and bycatch records derived from fisheries discard surveys can be used as a first step in interaction monitoring in order to identify hotspots of cetacean-fishery interactions (ICES, 2011b). Photo-identification studies, i.e. analysis of scars and injuries on cetaceans resulting from fisheries interactions, can help to identify conflicts on a more species- and gear-specific basis (Kiszka *et al*., 2008).

Observer schemes, i.e. direct vessel-based observations by marine mammal observers, are considered the most reliable methodology to obtain information on cetacean-fishery interactions, particularly to assess bycatch mortality. Since cetaceans spend most of their time underwater, direct observations from fishing vessels bear the risk to produce "false" absence records of a species at locations where it occurs but for some reason was not detected during data collection (Hirzel *et al*., 2002). This is particularly a problem for small and shy cetacean species, such as the harbour porpoise, which are difficult to detect at sea, even under calm sea conditions (Embling *et al*., 2010). The bias introduced through "false" absences within a dataset can, however, be controlled by including survey effort as a weighting factor in the model (MacLeod *et al*., 2008). If observations are made opportunistically (e.g. by fishers or fisheries observers), costs and logistical effort can be substantially reduced, but data reliability becomes even more doubtful. Since fishers/fisheries observers are usually busy with other tasks on-board, they are inevitably less efficient in detecting cetaceans at sea than dedicated observers.

Fishers and fisheries observers should also actively get involved in assessment and monitoring of interactions by means of interview surveys and logbooks. Qualitative research methods can be a valuable complementary tool to quantitative studies and allow for the assessment and monitoring of cetacean-fishery interactions on a large scale at comparatively low cost (White *et al*., 2005; Moore *et al*., 2010).

Fixed on-board cameras or small, disposable cameras provided to the crew (Marigo and Barros Giffoni, 2010) may be used to facilitate the documentation of cetacean-fishery interactions, particularly about the occurrence of dead cetaceans in fisheries catch (as recently trialled in several studies, see ICES, 2011b), and allow for more reliable results, especially concerning the identification of cetacean species and bycatch rates.

Monitoring cetaceans underwater can be accomplished with underwater cameras and passive acoustic monitoring instruments, such as hydrophones. These technical devices can be used to identify cetacean species approaching fishing gear/preying on catch, to assess depredation rates and to study the fine-scale behaviour of cetaceans around fishing gear (e.g. Read *et al*., 2003; Hernandez Milian *et al*., 2008). Obviously the disadvantage of this monitoring method is that the recording of video images and cetacean sounds is limited to a small, local survey area.

For the large-scale fishing fleet that has a small size when compared to the artisanal fleet, the placement of dedicated observer on fishing vessels may be financially viable and therefore provide the best solution for routine monitoring. In addition, fixed on-board video cameras should be used to document interactions. Static fishing gear, such as bottom-set longlines, may additionally be equipped with hydrophones and underwater cameras.

In small-scale fisheries, some combination of on-board observation by skippers/fisheries observers, interview surveys with fishers and the use of fixed on-board video cameras may represent the best financially and logistically feasible approach. Hydrophones and underwater cameras may be used by a few selected vessels in order to get further insights into the fine-scale behaviour of cetaceans around artisanal fishing gear.

6.4.3 IMPLICATIONS FOR FISHERIES AND CETACEAN CONSERVATION POLICY

Within the legal framework of the European Union, the mitigation and monitoring of cetacean-fishery interactions (particularly cetacean bycatch) is regulated mainly by three policies, EC Council Directive 56/2008 (Marine Strategy Framework Directive), EC Council Regulation 812/2004 laying down measures concerning incidental catches of cetaceans in fisheries and EC Council Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Fauna and Flora (Habitats Directive) (see also **Sections 1.5 and 1.7.1**).

Under the Marine Strategy Framework Directive, Member States have to develop a marine strategy that allows for the achievement (or maintenance) of a "good environmental status" of their marine areas. The European Commission has provided 11 qualitative descriptors for good environmental status of marine waters, one of them being biodiversity. Marine mammals (inter alia harbour porpoise and bottlenose dolphin) are listed as an important component of biodiversity and in order to achieve good environmental status, Member States must monitor their distribution, population size and population status. Bycatch mortality is one of the parameters to be assessed in relation to population status.

EC Council Regulation 812/2004 requires the compulsory presence of on-board observers on vessels ≥ 15 m operating trawls and set gillnets and the obligatory use of pingers for vessels ≥ 12 m fishing with set gillnets in specific fishing areas (including Atlantic waters of Spain and Portugal) within the European Union. The regulation thus basically covers medium- to large-scale fisheries where cetacean bycatch is assumed to be particularly high. The present work, however, suggests that cetaceans are also frequently bycaught in coastal, artisanal gillnets in Iberian Atlantic waters. In addition, catch loss and gear damage by cetaceans is mainly affecting coastal gillnet and purse seine fisheries. The Council Regulation states that cetacean bycatch and pinger use need to be assessed and monitored in scientific studies for the artisanal fleet, although no specific guidance (e.g. level of precision, coverage, methodologies) on monitoring is given. As a result, monitoring programmes and pilot projects for small-scale vessels, that make up the bulk of Galician and Portuguese fisheries (Galician Ministry of Fisheries, 2013; Portuguese Directorate General of Natural Resources, Security and Maritime Services, 2013), have generally been poorly implemented (ICES, 2011b). Since cetacean-related problems are apparent in these fisheries and may potentially increase over time, appropriate programmes to monitor cetacean-fishery interactions and possible mitigation methods should be established and legally implemented.

If pingers prove to be efficient in reducing interactions of cetaceans with purse seines and artisanal gillnets, without producing any significant negative effects on cetaceans and fisheries target species, their obligatory use may be considered for these fisheries. The technical specifications of pingers to be used in Community Fisheries are defined under the Council Regulation. They should have a source level of 130-150 dB re 1 μPa @ 1 m, a fundamental frequency of 10 – 160 kHz with high-frequency harmonics, a pulse duration of 300 ms and an interpulse interval of 4 – 30 s. The short pulse duration and interpulse interval, as well as the upper source level limit and lower frequency threshold specified under the Council Regulation minimize the probability that pingers can be heard by targeted fish and reduce the likelihood of any negative effect of pinger sounds on cetacean species with higher hearing sensitivity (e.g. habitat exclusion or hearing damage). In order to reduce the likelihood of cetacean habituation to the pingers, periodical changes in pinger sound frequencies and the use of responsive pingers (Leeney *et al*., 2007; Gazo *et al*., 2008) should be considered as an additional technical measure.

In large-scale trawl fisheries, the legal implementation of time/area restrictions to fishing activity may be thought of an additional measure to reduce cetacean bycatch.

Beach seines are frequently used along the Portuguese coast. In Galician fisheries, they are not employed. The present work suggests that harbour porpoises are more abundant in Portuguese than in Spanish Atlantic water. Since bycatch of harbour porpoise is particularly high in this fishing gear, a general prohibition of beach seine fishing should probably also be discussed to protect the small, genetically distinct harbour porpoise Iberian population (Fontaine *et al*., 2007; 2010). The results of the SCANS II survey for the surveyed block W (which comprises the Atlantic shelf waters of the Iberian Peninsula and extended partially onto the French shelf) gave an abundance estimate of 1474 individuals (CV=0.78) using mark-recapture line transect methods (SCANS II, 2008). A more recent estimate of 683 animals (CV=0.63, 95%CI: 345-951) was obtained by López et al. (2013) based on sightings recorded in the Galician and Cantabrian waters during 2003-2011. This latter estimate does not take into account availability, perception and responsive movement bias therefore the authors pointed out that the estimate is likely negatively biased but nonetheless highlights the small size of this population which the ICES Working Group on Marine Mammal Ecology (WGMME) proposed as a separate management unit (ICES, 2013).

Under the EC Habitats Directive, all cetaceans are strictly protected, i.e. deliberate killing, capture and disturbance are prohibited. Bottlenose dolphin and harbour porpoise are additionally identified as species requiring the designation of Special Areas of Conservation (SACs). The Southern Galician rías are inhabited by a resident bottlenose dolphin population, which differs both ecologically and genetically from bottlenose dolphins occurring off Northern Galicia and further offshore, and was also identified as a separate management unit in the 2013 report of ICES WGMME (ICES, 2013). Dolphins feeding inside the rías were found to have a broader diet than northern/offshore animals that were more dependent on shelf prey species, such as blue whiting (Fernández *et al*., 2011a). In addition, animals inhabiting the southern rías showed low levels of genetic diversity when compared to animals from neighbouring locations which suggests limited gene flow with outside areas (Fernández *et al*., 2011b). Similar residency patterns have been described for the very small and declining bottlenose dolphin population inhabiting the Sado Estuary (Figures 1.2, 6.1) in central continental Portugal (dos Santos and Lacerda, 1987; Augusto *et al*., 2011).

Bottlenose dolphins are reported to be bycaught in Spanish and Portuguese fisheries, although at significantly lower levels than common dolphins. Nevertheless, resident populations, due to their small size (using photoidentification standardized methodology from 2000-2010, García *et al.* (2011) identified a total of 255 individual bottlenose dolphins in Galician waters. A third of the photoidentified individuals (n = 76) were assigned by the authors as members of the resident population since this group included dolphins resighted several times. However, the low percentage of recaptures during this 10 year period led the authors to indicate that only a fraction of the coastal population had been identified; 24 animals in the Sado Estuary, Augusto *et al*., 2011) and genetic/ecologic isolation, may be impacted more severely by bycatch mortality, especially if they are additionally exposed to other threatening human activities such as overfishing, habitat degradation, pollution and boat traffic (Fernández *et al*., 2011b). This may also be the case for the small Iberian population of the harbour porpoise which is genetically distinct from other European populations (Fontaine *et al*., 2007, 2010) and, as mentioned above, has been suggested as a separate management unit by the ICES WGMME which recommended in 2010 that this population "should be given high priority for conservation". According to Read *et al*. (2012) and López *et al*. (2013), bycatch mortality of this species may be unsustainably high in North West and North Iberian waters and this fact has prompted the Scientific Committee of the IWC to strongly encourage Portuguese and Spanish authorities in its 2013 report to promote collaborative research projects towards obtaining unbiased estimates of both abundance and total bycatch for the harbour porpoise population of the Iberian Peninsula (IWC, 2013).

Under the EC Habitats Directive, SACs are defined as "*sites where the necessary conservation measures are applied for the maintenance or restoration, at a favourable conservation status, of the natural habitats and/or the populations of the species for which the site is designated*". Such conservation areas have the potential to protect cetacean populations with limited ranges (such as the resident bottlenose dolphin populations in the South Galician rías and the Sado Estuary and the Iberian porpoise population), given that they include important habitats (e.g. feeding, breeding and calving sites) and are sufficiently large to cover the range of the population concerned (Silva *et al*., 2012). The occurrence of bottlenose dolphin and harbour porpoise has been confirmed within 17 marine areas, presently designated as SCIs (Site of Community Importance) along the Northern Spanish and Portuguese Atlantic coast (ICNF, 2013; Spanish Ministry of Agriculture, Food and Environment, 2013b), but only one of these areas – the Le Danois Bank has been officially declared as SAC (Special Area of Conservation) to date (Figure 6.1). In order to define the conservation status of the protected cetacean species within the SAC, their distribution and population size, as well as human impacts (marine traffic, fishing activity, anthropogenic noise) need to be assessed (Real Decreto 1629/2011[17]).

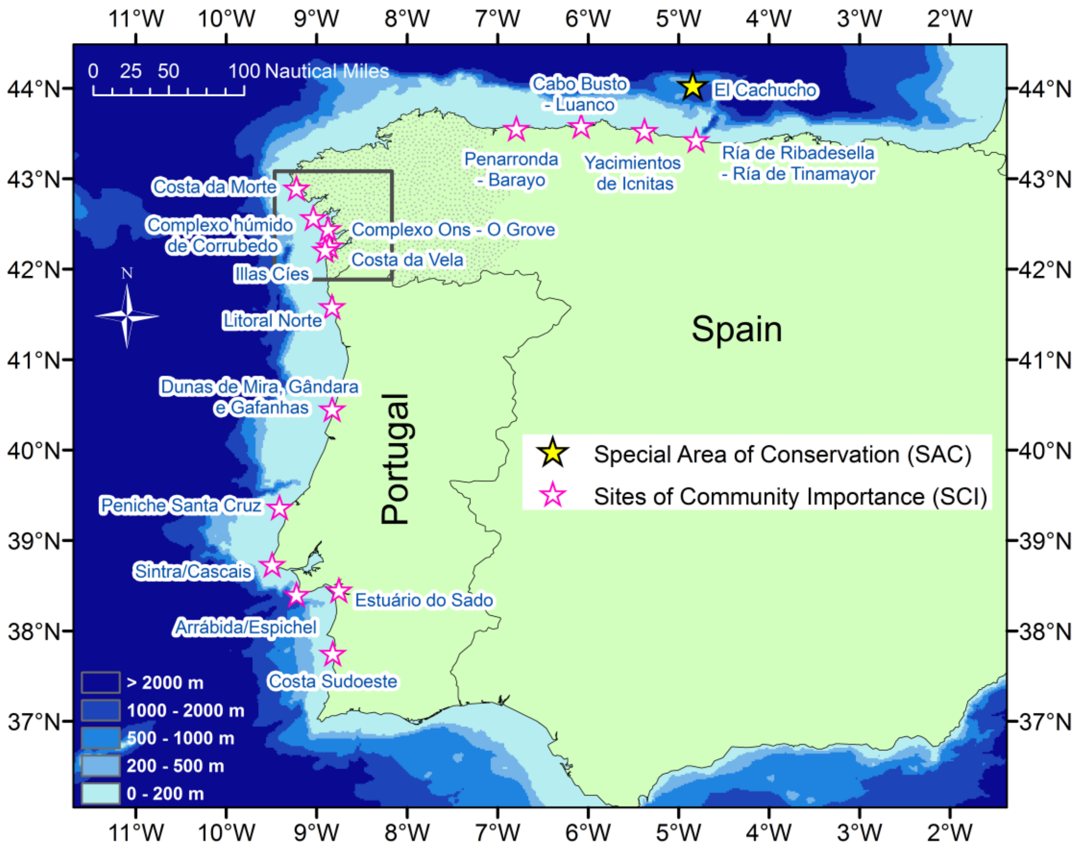


Figure 6.1. Sites of Community Importance (SCI) and Special Areas of Conservation (SAC) along the Iberian Atlantic coast. The *star symbol* indicates the geographic location of SCIs (*pink*) and SAC (*yellow*). The *dotted area* represents Galicia. The *black square* indicates the area of the Southern Galician rías. The main bathymetry is also displayed.

[17] **Real Decreto 1629/2011, de 14 de noviembre,** por el que se declara como Área Marina Protegida y como Zona Especial de Conservación el espacio marino de El Cachucho, y se aprueban las correspondientes medidas de conservación

The Sado Estuary in Portugal, with its resident population of bottlenose dolphins, is already included into the list of Portuguese SCIs, but the southern Galician rías, an important bottlenose dolphin habitat that is intensively used by humans, are not adequately covered by the marine areas identified as SCIs in NW Spain. Currently only a very small part of the southern rías are legally protected (Figure 6.2). The present work suggests that harbour porpoises are more abundant in Portuguese than in Spanish Atlantic water and that the common use of beach seines in Portuguese fisheries may lead to elevated mortality of this species.

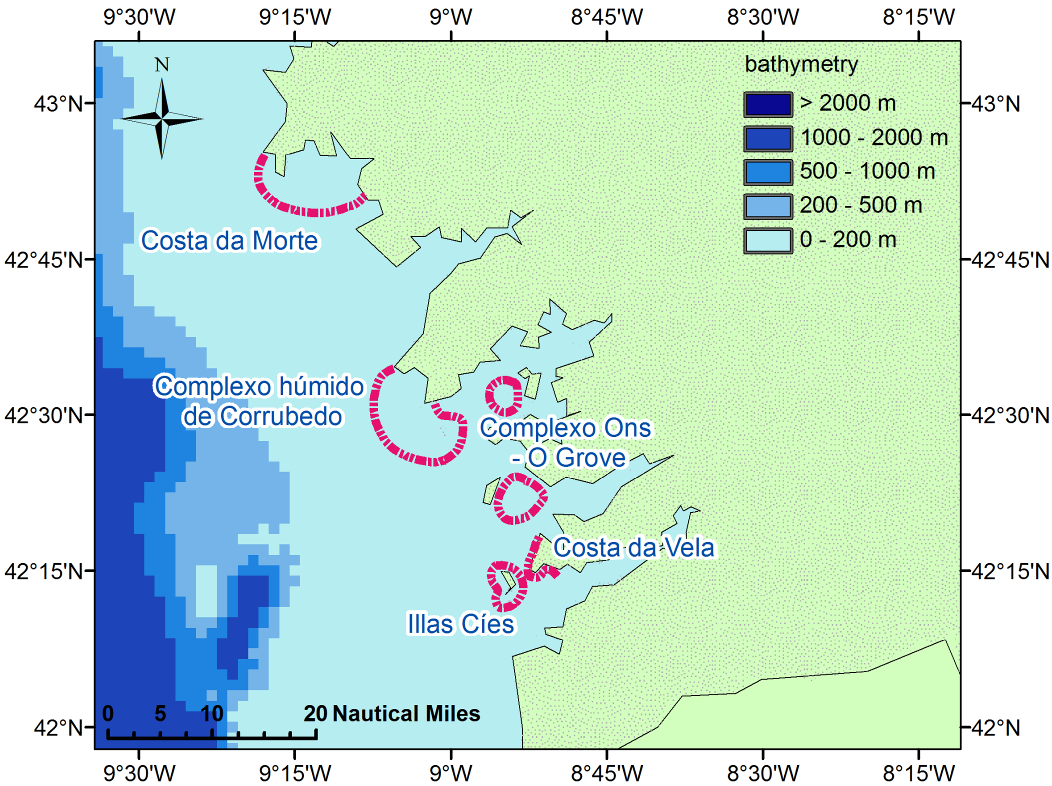


Figure 6.2. SCIs within the South Galician rías. The *pink dotted lines* indicate the area covered by each SCIs. The main bathymetry is also displayed.

The common dolphin is presently not included as protected species in any of the SCIs/SACs in Iberian Atlantic waters, although it is the cetacean species most frequently bycaught in the area. There is no evidence of separate populations of common dolphins in Iberian Atlantic waters and due to the wide ranges of this species, the creation of SACs may not be as efficient for their protection as for small, resident populations of bottlenose dolphins or the separate harbour porpoise population. However, conservation benefits may be achieved for this species if species-specific hotspots for bycatch (i.e. waters between 200-350 m depth with high trawling pressure) are taken into account in the designation of SCIs/SACs.

As a final remark, it is important to point out that the management of cetacean-fishery interactions is a multilayered, multidisciplinary issue, including conservation concerns, as well as socio-economic and political interests which are often in conflict with each other. Therefore communication with stakeholders through the establishment of partnerships and collaborative programs is a first important step for the successful implementation of a holistic management or mitigation strategy.

Fisher co-operation is another critical factor to improve current efforts to manage cetacean-fishery interactions. The behaviour of fishers, apart from economic interest, is also largely influenced by socio-cultural aspects. The willingness to accept and regularly apply a certain mitigation measure therefore depends on a variety of factors. Economic incentives that may result from the adoption of a certain mitigation measure may increase fishers' acceptance. This could, for instance, be higher catch rates, increased fishing efficiency through less gear damage and potential additional benefits arising from the commercialisation of eco-certified seafood. However, fishers need to be informed and convinced about these potential benefits. Field trials under "real conditions" should be carried out in active co-operation with fishers to assess the cost-benefit-ratio of mitigation strategies to be potentially adopted. The results of such trials need to be disseminated to other fishers, for instance during regular meetings or by distributing fact sheets in the harbours. There should always be an open dialogue with fishers about the performance of the mitigation measure and response to their feedback. Social and cultural aspects may also influence in the decision of fishers to take up mitigation measures. The collaboration with social scientists may contribute to a better understanding of such factors. Instead of imposing management actions on fishers, a bottom-up approach, i.e. the active participation of fishers in the development of mitigation measures, could facilitate the ultimate success of these measures.

Finally, legal enforcement is also believed to increase the uptake and compliance with mitigation measures. However, compliance control is often hindered in practice by the lack of resources available to management agencies to effectively enforce mitigation measures. In addition, current legislation provides only poor guidance about strategies and the amount of monitoring needed to control for compliance in each fishery. These problems should be considered in the revision of current and the formulation of future marine conservation policies.

6.5 FUTURE WORK

Although cetacean-fishery interactions have been widely assessed, there are still some knowledge gaps that should be addressed in future research.

Exact estimates of the number of cetaceans killed in fishing gear in Iberian Atlantic waters are needed in order to determine if bycatch rates exceed acceptable levels, threatening the viability of local cetacean populations. To achieve more reliable estimates of cetacean bycatch, a combination of measures will be needed. The possibility of voluntary reporting schemes (e.g. carcass recovery or logbooks) should be explored. Environmental education of fishers would be an essential pre-requisite of this approach, since many fishers may not perceive cetacean bycatch as an urgent ecological problem. Effective methods of communication with fishers need to be evaluated in order to ensure their co-operation in voluntary reporting schemes. Fishers should also be informed that landing of cetacean carcasses is legal (which is the case in Spain; in Portugal landing of bycaught cetaceans became illegal in 1982, but in some harbours landing may be authorized by the harbour authorities upon request) and that reporting bycatch will not have any negative consequences for them. In order to verify the information provided by fishers/fisheries observers, dedicated observer surveys should be conducted on some of the fishing vessels affected by interactions with cetaceans. This would allow for more accurate and reliable estimates of cetacean depredation, gear damage and bycatch in these fisheries. In this context, the utility of cameras (fixed on-board or on fishing gear) should also be assessed, especially in order to verify the cetacean species involved and to get insights into the fine-scale mechanisms of interactions, e.g. on how cetaceans remove fish from the gear, whether the fish are taken entirely or only partly and at what point during fishing cetacean bycatch usually occurs.

Future work should also be directed at the development, trial and improvement of existing and new methodologies to mitigate cetacean-fishery interactions and on the improvement of mechanisms to control fishers' compliance with legally enforced mitigation strategies.

Different models of pingers should be tested in long-term surveys in order to assess if cetacean habituation/sensitization occurs over time. This issue needs to be particularly investigated for the bottlenose dolphin. In addition, the potential of responsive and periodically modifiable pingers should also be evaluated in this context. In order to exclude negative impacts on catch rates, pinger trials should be also conducted with other important target species of fisheries. Further research should also focus on the development and improvement of acoustic deterrent devices with long emission ranges and functionality in deep waters to be applied in large-scale longline fisheries. Moreover, the willingness of local fishers to accept acoustic deterrent devices needs to be explored.

Research should also investigate if cetacean depredation occurs more frequently on acoustically reflective nets than on conventional nets and if time/area closures and vessel noise reduction are efficient measures to reduce cetacean-fishery interactions in Iberian Atlantic waters.

Physical depredation mitigation devices, such as net sleeves, need to be improved and trialled in further studies. In addition, the potential of dolphin exclusion devices, active decoys and trap fishing as an alternative fishing method should also be assessed in scientific studies.

Finally the viability of dolphin-watching activities and the eco-labelling of fisheries products should be evaluated in order to create socio-economically viable alternatives and supplementary sources of income for local fishers negatively affected by interactions with cetaceans.

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APPENDICES

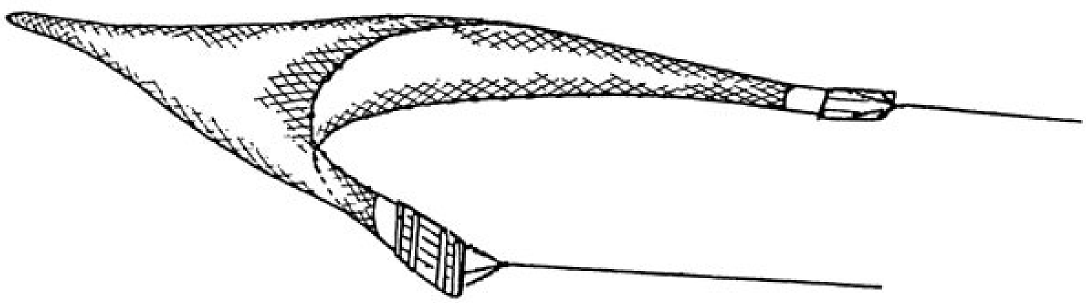
APPENDIX A

Description of fishing gear dealt with in this thesis

Trawls

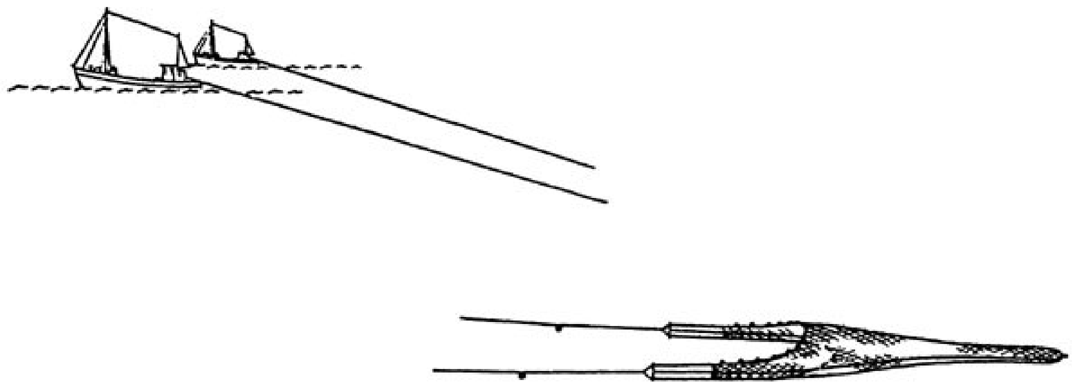
Trawls are towed nets comprising a conical body, ending at the back in a closed pocket (cod-end), where the captured fish accumulate, and extending frontwards with two wings of varying length. Trawling is an active fishing method and a general distinction can be made between bottom trawls that operate on the seabed and midwater/pelagic trawls that are towed in the water column.

Bottom otter trawls are towed by one boat. The horizontal opening of the net is controlled by two, fairly heavy divergent boards, fitted with steel footplates for closer contact with the seabed. Low-opening trawls are designed to target benthic and demersal species, while high-opening trawls mainly target semi-demersal and midwater species. The lower edge of the opening of the net is normally protected by a thick groundrope, weighted with chains and often fitted with rubber discs.



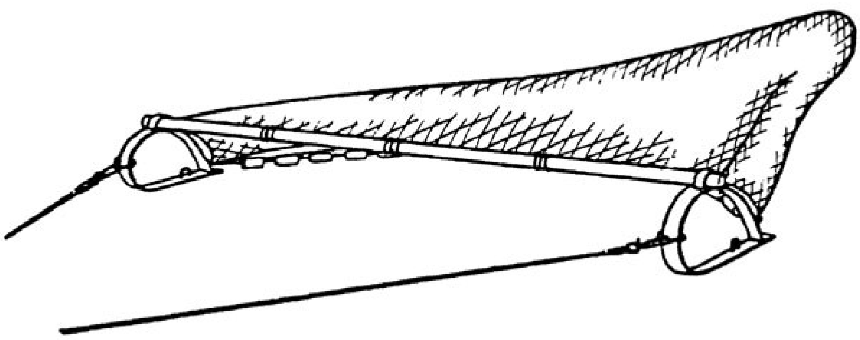
(drawing: FAO, 2013b)

Bottom pair trawls are towed simultaneously by two boats at a distance to ensure the horizontal opening of the net. The net itself does not differ notably from a bottom otter trawl, but there are no boards. The main target species are same as otter trawls, with a predominance of species living on the continental shelf, where pair trawlers usually operate.



(drawing: FAO, 2013b)

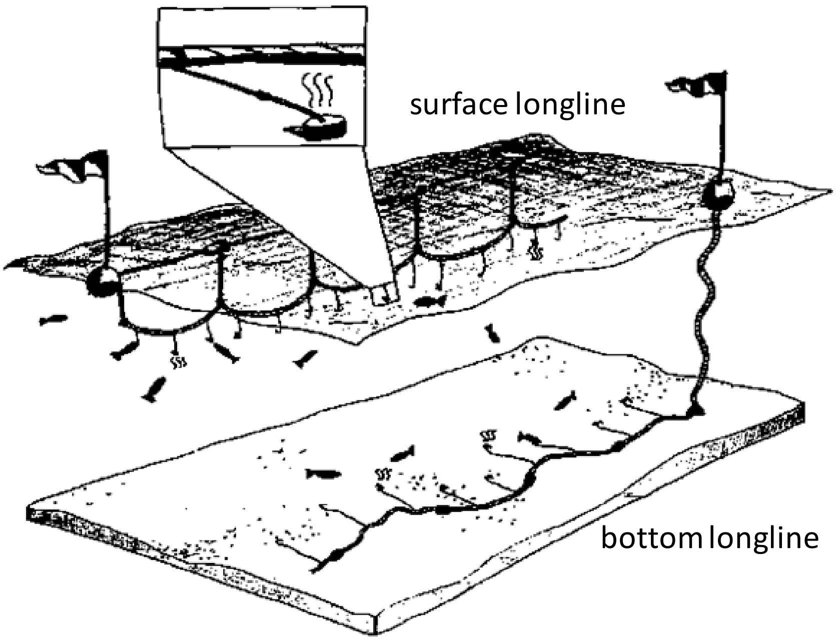
Bottom beam trawls are towed by one boat. The net is held open horizontally by a wood or metal beam and has a very small vertical opening, limited to the height of the trawl heads fixed to the sole plates at each end of the beam.



(drawing: FAO, 2013b)

Longlines

Longlines are composed of a main line and baited hooks which are attached to the main line at intervals by means of branch lines (snoods). Longlines are classified mainly by where they are placed in the water column, into **surface longlines** and **bottom-set longlines**. Longlines are usually set in the water for periods ranging from a few hours to several days. In small-scale fisheries, the lines are hauled by hand whilst in large-scale fisheries vessels are usually provided with powered line haulers, automatic jiggers, line reels, line coilers and automatic hook handling and baiting systems. In Galician fisheries, large-scale longlines can carry up to 6000 hooks, with a total line length of up to 20 km, while artisanal longlines are limited to 1700 hooks and a maximum length of 4 km (Decreto 15/2011[17] [Galician legislation]).

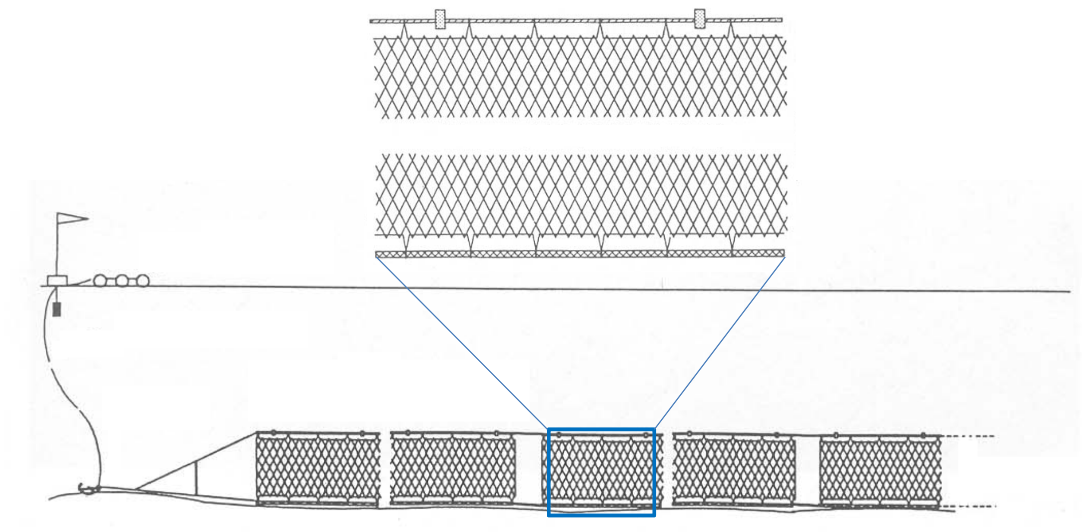


(drawing: FAO, 2013b)

[17] **Decreto 15/2011, de 28 de enero,** por el que se regulan las artes, aparejos, útiles, equipos y técnicas permitidos para la extracción profesional de los recursos marinos vivos en aguas de competencia de la Comunidad Autónoma de Galicia

Gillnets

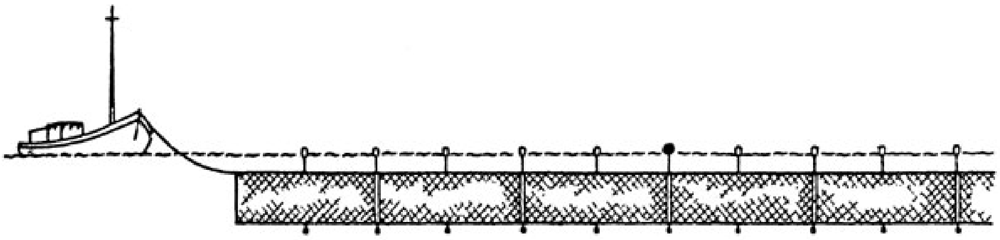
Single panel bottom-set gillnets consist of a single netting wall kept vertical by a float line (upper line/headrope) and a weighted ground line (lower line/footrope). The net is set on the bottom, or at a distance above it and held in place with anchors or weights on both ends. In Galician fisheries, several types of single panel bottom-set gillnets are used which differ concerning their dimension, mesh size and soak time. Large-scale fisheries use the so-called "volantas" (mesh size: 90 mm; net height: 10 m; net piece length: 50 m; maximum total length: 7 km) and "rascos" (mesh size: 250 mm; net height: 3.5 m; net piece length: 50 m; maximum total length: 11 km), while in small-scale fisheries smaller nets, so-called "betas" (mesh size: 60-80 mm; net height: 3 m; net piece length: 50 m; maximum total length: 4.5 km), are used.



front view

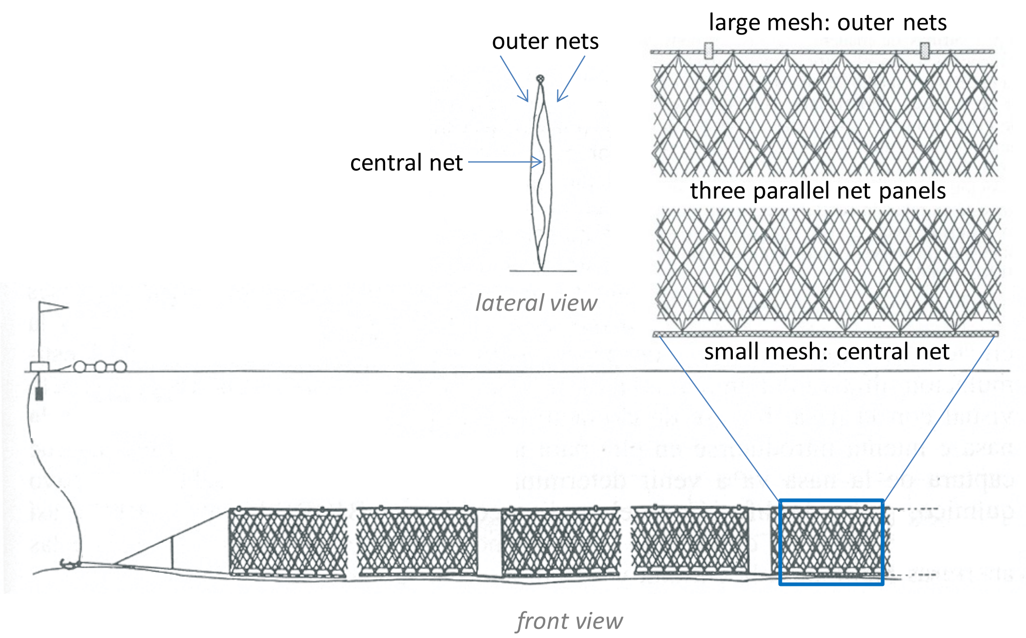
(drawing adapted from Puente, 1993)

Driftnets are single panel gillnets that are left free to drift with the current, usually near the surface or not far below it. Floats on the float line and weights on the ground line keep them vertical. They are usually connected to the operating vessel. In Galicia they are called "xeitos" and are only allowed in small-scale fisheries.



(drawing: FAO, 2013b)

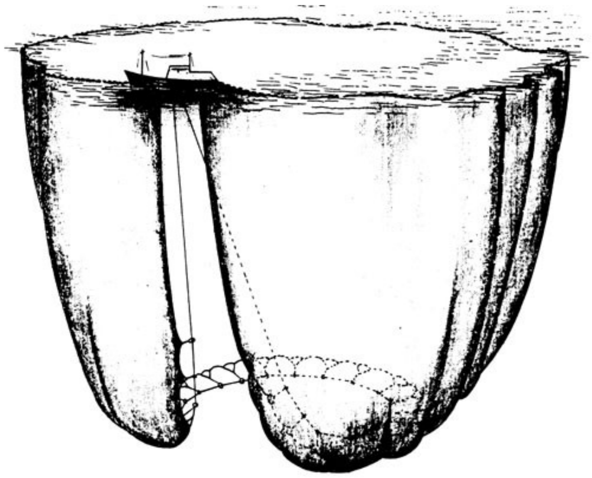
Trammel nets are composed of three layers of netting: a slack central layer with a small mesh size and two tense outer layers with larger meshes. In Galician fisheries, two types of artisanal trammel nets are used: the "trasmallos" (mesh size: 400 mm outer nets and 60 mm inner nets; net height: 2 m; net piece length: 50 m; maximum total length: 4.5 km) and "miños" (mesh size: > 500 mm outer nets and 90 mm inner nets; net height: 3 m; net piece length: 50 m; maximum total length: 4.5 km).



(drawing adapted from Puente, 1993)

Surrounding nets

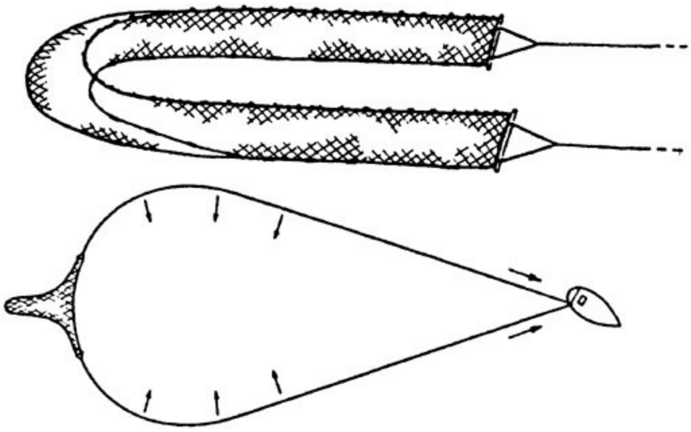
Purse seines are large single-panel multi-sectioned nets used to encircle pelagic fish, the bottom of which is then drawn together to enclose them. The purse seines, which may be very large, are operated by one or two boats. There are also specific measurements allowed for this type of net in Galicia.



(drawing: FAO, 2013b)

Seine nets

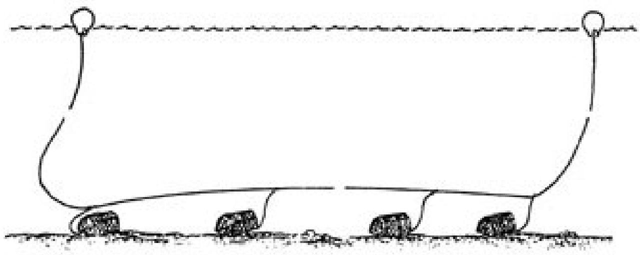
Seine nets are very long nets, with or without a bag in the centre, with two ropes fixed to its ends. The nets are set either from the shore (**beach seines**) or from a boat (**boat seines**), surrounding a certain area and herding the fish towards the beach/boat for hauling.



(drawing: FAO, 2013b)

Traps and pots

Traps and pots are gears in which the fish are retained or enter voluntarily and will be hampered from escaping. They are designed in such manner that the entrance itself became a non-return device, allowing the fish to enter the trap but making it impossible to leave the catching chamber. Traps are usually set on the bottom, with or without bait, connected by ropes. Traps used in Galician fisheries usually consist of a wood or metal frame, covered by net or netting wire. In Portugal, clay pots, so-called "alcatruzes" are used to catch octopus.



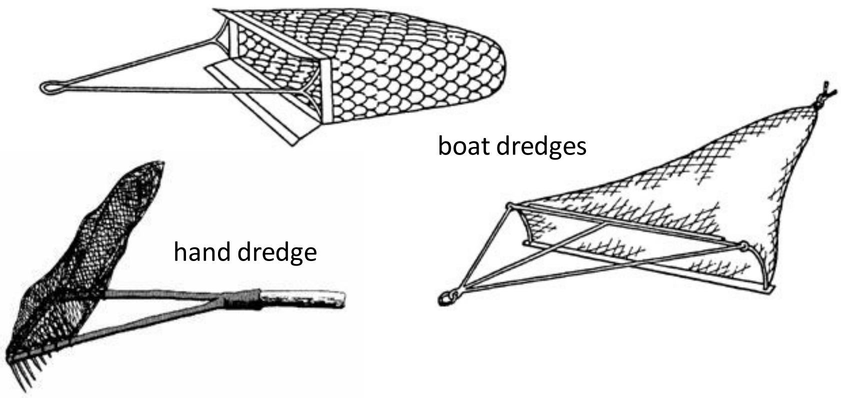
octopus traps

alcatruces

(drawing: FAO, 2013b)

Dredges

Dredges consist of a net bag or metal basket mounted on a frame of variable shape or size, the lower part of which carries a scraper blade, sometimes toothed. The gear is either towed by a steel wire rope to the boat (**boat dredge**) or pulled behind by hand (**hand dredge**).



(drawing: Castro, 1998; FAO, 2013b)

Table A.1. Multilingual fishing gear nomenclature (English, Spanish, Portuguese and Galician) and International Standard Statistical Classification of Fishing Gear (ISSCFG) (FAO, 1980)

	English gear name	Spanish gear name	Portuguese gear name	Galician gear name	ISSCFG Code
trawls	bottom beam trawl	red de arrastre de vara	rede de arrasto de vara	*small-scale*: bou de vara	TBB
	bottom otter trawl	arrastre de fondo con puertas	arrasto de fundo com portas	arrastre bou/vaca	OTB
	bottom pair trawl	arrastre de fondo a la pareja	arrasto de parelha	arrastre parella	PTB
longlines	surface longline	palangre de superfície	palangre de superfície	palangre de superfície	LLD
	bottom-set longline	palangre de fondo	palangre de fundo	*large-scale*: palangre de fondo *small-scale*: palangrillo	LLS
gillnets	single panel bottom-set gillnet	red de enmalle de fondo	red de emalhar fundeada	*large-scale*: volanta, rasco *small-scale*: beta	GNS
	driftnet	red de enmalle de deriva	red de emalhar de deriva	xeito	GND
	trammel net (3 panels)	trasmallo	red de emalhar de tresmalho	trasmallo, miño	GTR
surrounding nets	purse seine	cerco	cerco	cerco	PS
seines	boat seine	red de tiro desde embarcación	rede envolvente-arrastante de alar para bordo	bou de man, boliche	SV
	beach seine	arte de playa jávega, boliche	xávega	xávega	SB
traps	traps and pots	trampas y nasas	armadilhas de abrigo, alcatruzes	nasas	FPO
dredges	boat dredge	draga para embarcación	draga rebocada por embarcção	endeño remolcado, can	DRB
	hand dredge	rastra de mano, angazo	draga de mão	rastro, angazo	DRH

APPENDIX B

Names of species (fisheries resources, cetaceans and seabirds) mentioned in this thesis

Table B.1. Multilingual nomenclature of fish species mentioned in this thesis (in Latin, English, Spanish, Portuguese, and Galician) and their international code (Inter-Agency 3-Alpha Identifier)

	Latin name	English common name	Spanish common name	Portuguese common name	Galician common name	Code
Class: Chondrichthyes						
Subdivision: Selachii						
Order: Lamniformes	*Isurus oxyrinchus*	shortfin mako	marrajo dientuso	tubarão-anequim	marraxo azul	SMA
Order: Carcharhiniformes	*Prionace glauca*	blue shark	tiburón azul	tintureira	quenlla	BSH
	Scyliorhinus spp	catsharks, nursehounds	alitanes, pintarrojas	pata-roxas	melgachos	SCL
Subdivision: Batiodea						
Order: Rajiformes	*Raja spp*	skates nei	rayas raja nep	raias	raias	SKA
Class: Actinopterygii						
Order: Anguilliformes	*Conger conger*	European conger	congrio común	congro/safio	congro	COE
Order: Clupeiformes	*Alosa alosa*	allis shad	sábalo común	sável	zamborca	ASD
	Alosa sapidissima	American shad	sábalo americano	sável-americano		
	Clupea harengus	Atlantic herring	arenque del Atlántico	arrenque	arenque do Atlántico	HER
	Engraulis encrasicolus	European anchovy	anchoa	biqueirão	bocarte	ANE
	Harengula jaguana	scaled sardine	Sardineta	sardineta		SAS
	Sardina pilchardus	European pilchard (sardine)	sardina europea	sardinha	sardiña	PIL
	Sardinella aurita	round sardinella	alacha	sardinela-lombuda		NED
Order: Lophiiformes	*Lophius spp*	monkfish	rapes	tamboris	peixe sapos	MNZ
	Lophius piscatorius	angler (monk)	rape	tamboril	xuliana	MON
Order: Gadiformes	*Gadiculus argenteus*	silvery pout	faneca plateada	badejinho		GDG
	Macruronus magellanicus	Patagonian grenadier	merluza de cola patagonica	granadeiro-da-Patagónia	pescada de cola austral	GRM
	Merlangius merlangus	whiting	plegonero	badejo	mendo limon	WHG
	Merluccius hubbsi	Argentine hake	merluza argentina	pescada-argentina	pescada arxentina	HKP
	Merluccius merluccius	European hake	merluza europea	pescada-branca	pescada	HKE
	Micromesistius australis	Southern blue whiting	bacaladilla austral	verdinho-austral	lirio austral	POS
	Micromesistius poutassou	blue whiting (poutassou)	bacaladilla	verdinho	lirio	WHB
	Phycis spp	forkbeards	brótolas	abróteas	bertorellas	FOX

	Latin name	English common name	Spanish common name	Portuguese common name	Galician common name	Code
	Pollachius pollachius	pollack	abadejo	juliana	abadexo	POL
	Trisopterus luscus	pouting (bib)	faneca	faneca	faneca	BIB
Order: Mugiliformes	*Chelon labrosus*	thicklip grey mullet	lisa	tainha-liça	muxo negro	MLR
	Mugil spp	mullet		tainhas	muxos	MGS
Order: Beloniformes	*Belone belone*	garfish	aguja	peixe agulha	agulla	GAR
Order: Zeiformes	*Capros aper*	boarfish	ochavo	pimpim		BOC
Order: Syngnathiformes	*Macroramphosus scolopax*	longspine snipefish	trompetero	trombeteiro (apara-lápis)	trompeteiro	SNS
Order: Pleuronectiformes	*Dicologlossa cuneata*	wedge sole	acedía	língua	acedía	CET
	Lepidorhombus spp	megrims nei	gallos nep	areeiros	rapantes	LEZ
	Microchirus spp	thickback soles	golletas	azevias		THS
	Pleuronectes platessa	European plaice	solla europea	solha	solla de altura	PLE
	Psetta maxima	turbot	rodaballo	pregado	rodaballo	TUR
	Solea solea	common sole	lenguado común	linguado-legítimo	linguado	SOL
Order: Scorpaeniformes	*Scorpaena scrofa*	red scorpionfish	cabracho	rascasso-vermelho	escarapote de pedra	RSE
Order: Perciformes						
Suborder: Percoidei	*Dentex dentex*	common dentex	dentón	capatão-legítimo	dentón	DEC
	Dicentrarchus labrax	European seabass	lubina	robalo-legítimo	robaliza	BSS
	Diplodus sargus	white seabream	sargo	sargo-legítimo	sargo común	SWA
	Dissostichus eleginoides	Patagonian toothfish	austromerluza negra	marlonga-negra	pescada negra	TOP
	Labrus bergylta	ballan wrasse	maragota	bodião-reticulado	maragota	USB
	Mullus surmuletus	red mullet	salmonete de roca	salmonete-legítimo	salmonete de rocha	MUR
	Pagellus bogaraveo	blackspot (red) seabream	besugo	goraz	ollomol	SBR
	Trachurus spp	jack and horse mackerels	jureles nep	carapaus	xurelos	JAX
	Trachurus trachurus	Atlantic horse mackerel	jurel	carapau	xurelo	HOM
Suborder: Scombroidei	*Aphanopus carbo*	black scabbardfish	sable negro	peixe-espada preto	peixe sabre negro	BSF
	Scomber scombrus	Atlantic mackerel	caballa del Atlántico	sarda	xarda	MAC
	Thunnus thynnus	Northern bluefin tuna	atún común (cimarrón)	atum-rabilho	atún vermello	BFT
	Xiphias gladius	swordfish	pez espada	espadarte	peixe-espada	SWO

Table B.2. Multilingual nomenclature of crustacean and cephalopod species mentioned in this thesis (in Latin, English, Spanish, Portuguese and Galician) and their international code (Inter-Agency 3-Alpha Identifier)

	Latin name	English common name	Spanish common name	Portuguese common name	Galician common name	Code
Class: Branchiopoda						
Order: Anostraca	Artemia spp	brine shrimp	artemia	artêmia		
Class: Malacostrata						
Order: Decapoda	*Aristeus antennatus*	blue and red shrimp	gamba rosada	camarão-vermelho	gamba rosada	ARA
	Palaemon serratus	common prawn	camarón común	camarão-branco-legítimo	camarón común	CPR
	Parapenaeus longirostris	deep-water rose shrimp	gamba de altura	gamba-branca	gamba branca	DPS
	Cancer pagurus	edible crab	buey de mar	sapateira	boi	CRE
	Carcinus maenas	green crab	cangrejo verde	caranguejo-verde	cangrexo común	CRG
	Maja squinado	spinous spider crab	centolla europea	santola-europeia	centola	SCR
	Necora puber	velvet swimcrab	nécora	navalheira-felpuda	nécora	LIO
	Homarus spp	lobster	bogavantes	lavagantes	lumbrigantes	LBS
	Homarus gammarus	European lobster	bogavante	lavagante	lumbrigante	LBE
	Nephrops norvegicus	Norway lobster	cigala	lagostim	cigala	NEP
	Palinurus elephas	common spiny lobster	langosta común	lagosta-castanha	lagosta	SLO
	Pleoticus muelleri	prawn	gambon austral	camarão-vermelho-argentino	gamba vermella arxentina	LAA

Table B.3. Multilingual nomenclature of mollusc species mentioned in this thesis (in Latin, English, Spanish, Portuguese and Galician) and their international code (Inter-Agency 3-Alpha Identifier)

	Latin name	English common name	Spanish common name	Portuguese common name	Galician common name	Code
Class: Cephalopoda						
Order: Myopsida	*Loligo vulgaris*	European squid	calamar	lula	lura	SQC
Order: Octopoda	*Octopus vulgaris*	common octopus	pulpo	polvo	polbo	OCC
Order: Oegopsida	*Illex argentinus*	Argentine shortfin squid	pota argentina	pota-argentina	pota arxentina	SQA
Order: Sepiida	*Sepia officinalis*	common cuttlefish	sepia	choco	choco	CTC

Table B.4. Multilingual nomenclature of cetacean species mentioned in this thesis (Latin, English, Spanish, Portuguese and Galician)

	Latin name	English	Spanish	Portuguese	Galician
Order: Cetacea					
Suborder: Mysticeti					
Family: Balaenopteridae	*Balaenoptera acutorostrata*	minke whale	rorcual común	baleia-anã	balea
Suborder: Odontoceti					
Family: Delphinidae	*Cephalorhynchus commersonii*	Commerson's dolphin	delfín de Commerson	golfinho-de-commerson	toniña overa
	Delphinus delphis	short-beaked common dolphin	delfín común	golfinho-comum	golfiño común
	Globicephala melas	long-finned pilot whale	calderón común	baleia piloto	caldeirón
	Grampus griseus	Risso's dolphins	delfín gris	grampo	arroaz boto
	Lagenorhynchus obscurus	dusky dolphin	delfin oscuro	golfinho-do-crepúsculo	golfiño escuro
	Lissodelphis peronii	Southern right whale dolphin	delfín liso del sur	golfinho-liso-do-sul	golfiño liso
	Orcinus orca	killer whale	orca	orca	candorca
	Pseudorca crassidens	false killer whale	falsa orca	falsa-orca	falsa candorca
	Stenella coeruleoalba	striped dolphin	delfín listado	golfinho-riscado	golfiño
	Stenella frontalis	Atlantic spotted dolphin	delfín manchado	golfinho-pintado-do-atlântico	golfiño pintado
	Tursiops truncatus	common bottlenose dolphin	delfín mular	roaz corvineiro	arroaz
Family: Phocoenidae	*Phocoena phocoena*	harbour porpoise	marsopa	bôto	toniña
Family: Physteridae	*Physeter macrocephalus*	sperm whale	cachalote	cachalote	cachalote
Family: Ziphidae	*Mesoplodon layardii*	strap-toothed whale	Zifio de Layard	baleia-bicuda-de-layard	cifio de Layard

Table B.5. Multilingual nomenclature of seabird species mentioned in this thesis (Latin, English, Spanish and Portuguese)

	Latin name	English common name	Spanish common name	Portuguese common name
Order: Procellariiformes				
Family: Diomedeidae	*Diomedea epomophora*	Southern royal albatross	albatros real	albatroz-real-meridional
	Diomedea exulans	wandering albatross	albatros errante	albatroz-errante
	Thalassarche chrysostoma	grey-headed albatross	albatros de cabeza gris	albatroz-de-cabeça-cinza
	Thalassarche melanophrys	black-browed albatross	albatros de ceja negra	albatroz-de-sobrancelha
Family: Procellariidae	*Daption capense*	cape petrel	petrel damero	pintado
	Macronectes giganteus	Southern giant petrel	petrel gigante antártico	petrel-gigante
	Macronectes halli	Northern giant petrel	petrel gigante subantártico	petrel-gigante-do-norte
	Procellaria aequinoctialis	white-chinned petrel	petrel negro	pardela preta
	Puffinus gravis	great shearwater	pardela capirotada	pardela-de-bico-preto
	Puffinus puffinus	manx shearwater	pardela pichoneta	pardela-sombria
Family: Hydrobatidae	*Fregetta tropica*	black-bellied storm petrel	paíño ventrinegro	painho-de-barriga-preta
	Oceanites oceanicus	Wilson's storm petrel	paíño de Wilson	painho-casquilho

APPENDIX C

Some examples of technical measures to mitigate cetacean-fishery interactions

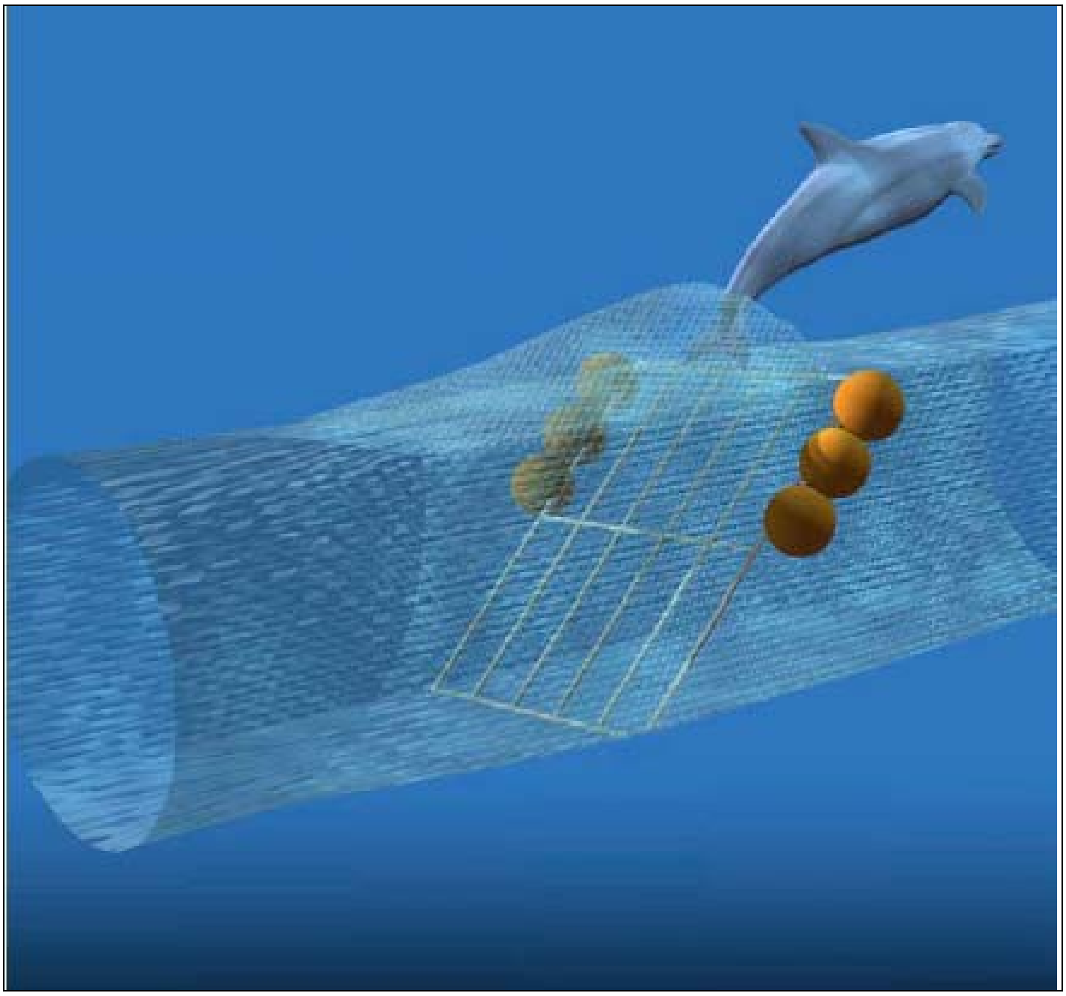


Figure C.1. Diagram of a dolphin exclusion device. (Figure from Northridge, 2003)

Figure C.2. Four models of commercially available pingers (from top to bottom): Aquamark 210 (Aquatec Subsea Ltd.), Marexi V2.2 (Marexi Marine Technology), Fumunda F10 and F70 (Fumunda Marine).

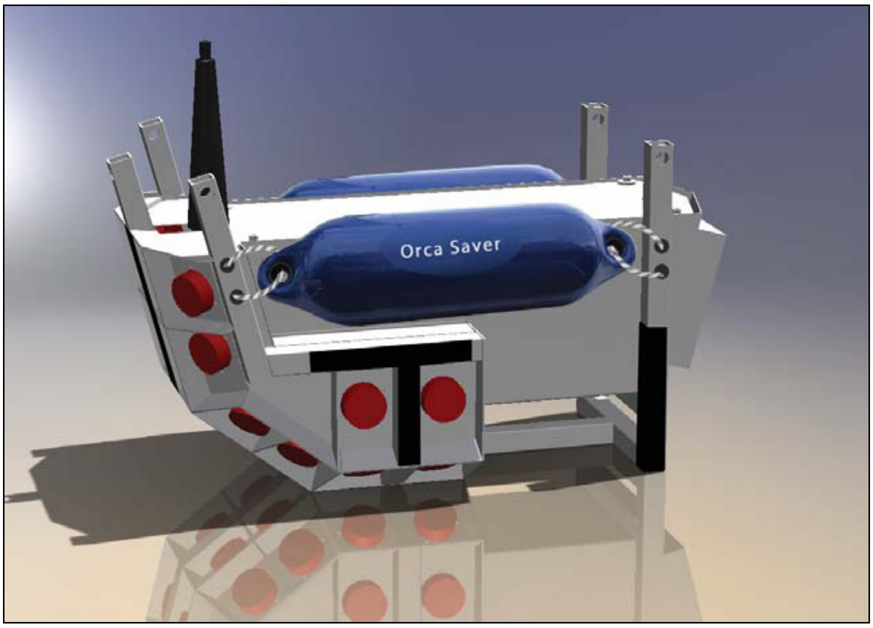


Figure C.3. Acoustic harassment device (AHD) "OrcaSaver™" fabricated by Mustad Longlines AS http://mustad-autoline.com/products/orcas_saver/

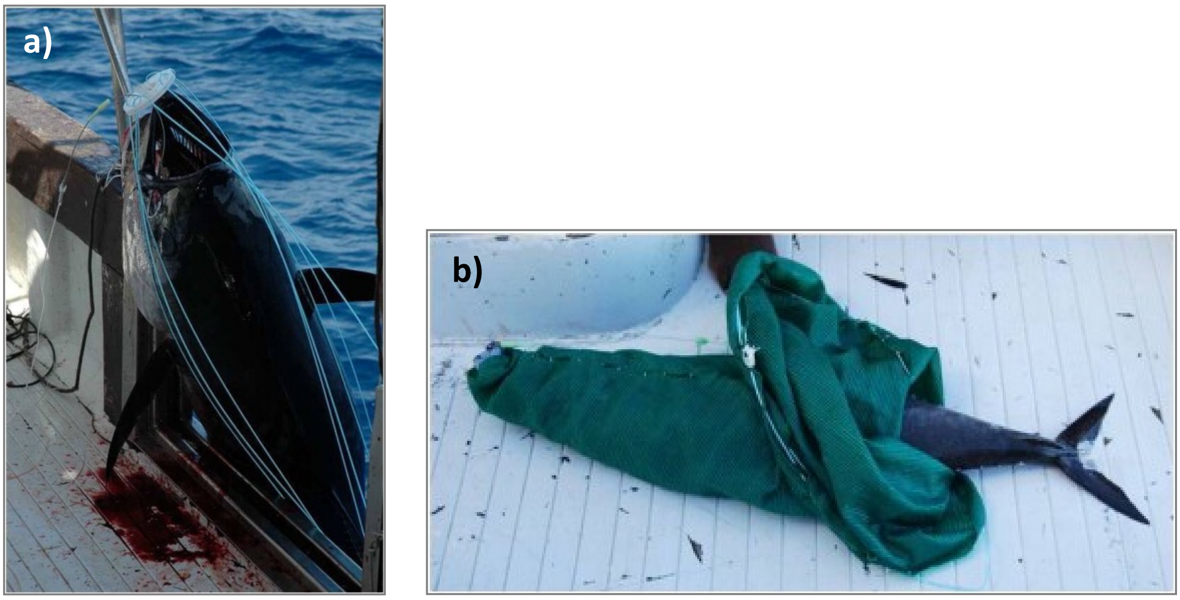


Figure C.4. Physical depredation mitigation devices used in pelagic longline fisheries (pictures taken from Rabearisoa *et al*., 2012), the so-called a) "spider" and b) "sock"

APPENDIX D

Questionnaire used for the interview survey presented in this thesis (translated into English)

SIGHTINGS/ INTERACTIONS OF CETACEANS WITH FISHERIES

☐ **interview code**

Date __________ **Harbour**_______________ **Interviewer**______________

This questionnaire is designed to find out a few things about your job, fisheries in Galicia in general and the interactions of cetaceans (dolphins, porpoises and whales) with these fisheries. Please answer the questions truthfully. There are no right or wrong answers.

This work is for statistical purposes only. All information will be treated confidentially and will not be distributed to a third party

(*please fill in the relevant box or tick one or more answers*)

1. What is your function on board of the vessel?

☐ skipper ☐ sailor ☐ mechanic ☐ other______________

2. What kind of fishing gear do you use?

☐ pair trawl _________________________
☐ otter trawl _________________________
☐ bottom longline ____________________
☐ surface longline ____________________
☐ gillnets *(specify type)* _________
☐ purse seine ________________
☐ pots _____________________
☐ other _____________________

3. What length/tonnage/crew has the vessel ?
(indicate just one)

☐ meters ☐ tons ☐ crew members

4. In which area are you fishing?

Fishing area

☐ inside the rías

☐ outside of rías

Sub-area

☐ 1 Ría Ribadeo - Estaca de Bares
☐ 2 Estaca de Bares - Pta. Segaño (S ría Ferrol)
☐ 3 Pta. Segaño - Cabo Fisterra
☐ 4 Cabo Fisterra - Cabo Corrubedo
☐ 5 Cabo Corrubedo - Cabo Home
☐ 6 Cabo Home - Río Miño
☐ other _____________________

Mean distance to coast (m/nm): ___________
Mean water depth (m/fathoms): ___________

5. What time do you leave for fishing?

6. What time do you return to the harbour?

7. Which are your main target species ?

Fish			
☐ Abadexo	☐ Castañeta	☐ Maragota/Pinto	☐ Rapante
☐ Acedía	☐ Cazón	☐ Marraxo	☐ Robaliza
☐ Agulla	☐ Choupa	☐ Maruca	☐ Rodaballo
☐ Alavanco	☐ Congro	☐ Melga	☐ Saboga
☐ Anchoa/Bocareu	☐ Coruxo	☐ Mero	☐ Salmón
☐ Anguía	☐ Doncella	☐ Muxo	☐ Salmonete
☐ Barbada	☐ Dourada	☐ Palometa roja	☐ Sanmartiño
☐ Bertorella	☐ Escacho	☐ Peixe espada	☐ Sardiña
☐ Besugo/Ollomol	☐ Escarapote	☐ Peixe pao	☐ Sargo
☐ Boga	☐ Escolar	☐ Peixe sabre	☐ Serrán
☐ Bolo	☐ Faneca	☐ Peixe sapo	☐ Solla
☐ Bonito	☐ Fodón	☐ Pescada(illa)/Merluza	☐ Xarda/Cabala
☐ Burro	☐ Fogoneiro	☐ Piarda	☐ Xuliana
☐ Cabalón	☐ Gata	☐ Prago	☐ Xurelo
☐ Cabra	☐ Linguado	☐ Quenlla	☐ mixture
☐ Cabracho	☐ Lirio	☐ Raia	☐ __________

Bivalves		**Cephalopods**	**Crustaceans**	**Other**
☐ Ameixa	☐ Mexillón	☐ Cabezón	☐ Boi	☐ _________
☐ Berberecho	☐ Navalla	☐ Choco	☐ Camarón	☐ ________
☐ Cadelucha	☐ Ostra	☐ Chopiño	☐ Cigala	☐ ________
☐ Carneiro	☐ Rabioso	☐ Lura	☐ Lagosta	☐ ________
☐ Centola	☐ Reló	☐ Polbo	☐ Lumbrigante	☐ ________
☐ Cornicha	☐ Vieira	☐ Pota	☐ Nécora	☐ ________
☐ Longueirón	☐ Volandeira	☐ Puntilla	☐ Percebe	☐ ________

8. What is your average catch ? ☐ don't know

☐ **per haul** ☐ **per trip** ☐ **last trip**

(indicate just one; if average catch cannot be estimated, indicate amount of catch for last trip)

total in kg (tons) _________ in crates________

(for each target species)

________________ in kg (tons)_________ in crates________

________________ in kg (tons)_________ in crates________

________________ in kg (tons)_________ in crates________

-> weight of each crate (kg) ___________

9. Do you usually see dolphins and whales in your fishing area?

☐ yes ☐ no -> *if answer is no, go to question **36***

10. What kind of dolphins and whales do you see and how many? Do you see them frequently? don't know ☐

(pres = present; N° = number of individuals; freq = frequent; rare)

	pres	N°	freq	rare		pres	N°	freq	rare
non-identified (NI) dolphins	☐	☐	☐	☐	pilot whale	☐	☐	☐	☐
common dolphin	☐	☐	☐	☐	sperm whale	☐	☐	☐	☐
bottlenose dolphin	☐	☐	☐	☐	killer whale	☐	☐	☐	☐
striped dolphin	☐	☐	☐	☐	baleen whales	☐	☐	☐	☐
Risso's dolphin	☐	☐	☐	☐	other ______	☐	☐	☐	☐
harbour porpoise	☐	☐	☐	☐	____________	☐	☐	☐	☐

ID correct? ☐ yes ☐ no

(Write down other common species names used by local fishers)

____

11.Do you think the number of dolphins/whales in the area has....during the last 5 years?

☐ increased ☐ decreased ☐ been constant ☐ don't know

12. What are your general feelings about dolphins/whales?

☐ positive ☐ negative ☐ neutral ☐ don't know

Why?____

13. Do you use the presence of dolphins/whales to locate fish?

☐ yes ☐ no ☐ don't know

14. Are the dolphins/whales seen in close proximity to the gear during fishing operation??

☐ yes ☐ no ☐ don't know

15. If yes, which species ? ☐ don't know

☐ NI dolphins ☐ striped dolphin ☐ pilot whale ☐ baleen whales
☐ common dolphin ☐ Risso's dolphin ☐ sperm whale ☐ other ______
☐ bottlenose dolphin ☐ harbour porpoise ☐ killer whale

16. Do the dolphins/whales and/or other animals consume catch ? ☐ don't know

☐ yes ☐ dolphins/whales -> *go to question **17***
☐ other animals -> *go to question **18***
☐ no -> *if answer is no/don't know, go to question **21***

17. Which species of dolphins/whales? ☐ don't know

☐ NI dolphins ☐ striped dolphin ☐ long-finned ☐ baleen whales
☐ common dolphin ☐ Risso's dolphin ☐ sperm whale ☐ other ______
☐ bottlenose dolphin ☐ harbour porpoise ☐ killer whale

18. Which other animals? ☐ don't know

---

19. Can you estimate the proportion of catch damaged/consumed?

☐ no ☐ yes % of catch per trip (by dolphins/whales) ☐
% of catch per trip (other animals) ☐
☐ there is none

20. Can you estimate the economic loss associated with this catch damage/loss?

☐ no ☐ yes by dolphins/whales ☐ per ☐ trip ☐ year
by other animals ☐ per ☐ trip ☐ year
☐ there is none

21. Do the dolphins/whales and/or other animals cause damage in the gear?

don't know ☐

☐ yes ☐ dolphins/whales -> *go to question **22***

☐ other animals -> *go to question **23***

☐ no -> *if answer is no/don't know, go to question **27***

22. Which species of dolphins/whales? ☐ don't know

☐ NI dolphins	☐ striped dolphin	☐ pilot whale	☐ baleen whales
☐ common dolphin	☐ Risso's dolphin	☐ sperm whale	☐ other ______
☐ bottlenose dolphin	☐ harbour porpoise	☐ killer whale	

23. Which other animals ☐ don't know

____

24. What kind of damage do the dolphins/whales cause? ☐ don't know

☐

25. What kind of damage do other animals cause? ☐ don't know

☐

26. Can you estimate the economic loss associated with this gear damage?

☐ no ☐ yes by dolphins/whales ☐ per ☐ trip ☐ year

☐ there is none by other animals ☐ per ☐ trip ☐ year

27. Are dolphins/whales accidentally bycaught?

☐ yes ☐ no ☐ don't know

-> *if answer is no/don't know, go to question **34***

28. Which species of dolphins/whales and how many ☐ don't know

	month year		month year		month year		month year
NI dolphins	☐☐	striped dolphin	☐☐	pilot whale	☐☐	baleen whales	☐☐
common dolphin	☐☐	Risso's dolphin	☐☐	sperm whale	☐☐	other _____	☐☐
bottlenose dolphin	☐☐	harbour porpoise	☐☐	killer whale	☐☐		

29. Are animals bycaught usually dead or alive when you haul the gear?

☐ alive ☐ dead ☐ don't know -> *if answer is dead go to question* ***31***

30. Do they survive?

☐ yes ☐ no ☐ don't know

31. What do you do with the carcasses? ☐ don't know

☐ bring them back to the harbour ☐ throw them back into the sea ☐ other________

32. Do you think the amount interactions with dolphins/whales has...during the last 5 years?

☐ increased
☐ decreased
☐ been constant
☐ don't know

33. Is there a season with more bycatch?

☐ yes ☐ no ☐ don't know -> *if answer is no/don't know, go to question* ***34***

Which season?____

34. Do you take any measures to avoid interactions(damage to catch/gear and bycatch) with dolphins/whales?

☐ yes ☐ no -> *if answer is no, go to question* ***36***

35. What type of measures?

☐ acoustic devices *(specify)*____
☐ navigate to alternative fishing grounds away from the dolphins/whales
☐ postpone the fishing operation until the dolphins/whales leave the area
☐ reduce the fishing/soak time
☐ scare the cetaceans away from the vessel *(specify)* ________________________
☐ other *(specify)* ____

36. In your opinion, what are the main problems with dolphins/whales and fisheries? (Fill in 3 boxes according to their importance: 1 – most important, 3- least important)

- ☐ don't know
- ☐ there are no problems
- ☐ the dolphins/whales damage the gear
- ☐ the dolphins/whales damage the catch
- ☐ the dolphins/whales cause additional costs, e.g. fuel costs from changing fishing grounds
- ☐ the dolphins/whales scatter the fish
- ☐ the dolphins/whales eat too many fish, i.e. competition for resources
- ☐ there is too much bycatch of dolphins/whales
- ☐ other *(specify)* ____

37. In your opinion, what are the most important factors influencing the amount of interactions (damage to catch/gear and bycatch) with dolphins/whales?

- ☐ don't know
- ☐ there are no factors
- ☐ fishing time, e.g. day or night/duration
- ☐ catch target species
- ☐ fishing area
- ☐ water depth
- ☐ season
- ☐ type of fishing gear
- ☐ weather
- ☐ behaviour of dolphins/whales
- ☐ other *(specify)*____

39. What are your suggestions to reduce conflicts between dolphins/whales and fisheries?

Some personal information……

How old are you? ____ How many years of working experience do you have? ____

Do you have family links with fisheries? ☐ yes ☐ no

☐ **male** ☐ **female**

Comments:

APPENDIX E

Research article about interactions of cetaceans with commercial surface longlines in Atlantic waters, published previous to this thesis.

Hernandez Milian,G., Goetz, S., Varela Dopico, C., Rodriguez Gutierrez, J., Romón Olea, J., Fuertes Gamundi, J.R., Ulloa Alonso, E., Tregenza, N.J.C., Smerdon, A., Otero, M.G., Tato, V., Wang, J., Santos, M.B., López, A., Lago, R., Portela, J.M., Pierce, G.J. 2008. Results of a short study of interactions of cetaceans and longline fisheries in Atlantic waters: environmental correlates of catches and depredation events.
Hydrobiologia 612: 251-268

The second author's contribution to this publication included data analysis and publication writing.

Hydrobiologia (2008) 612:251–268
DOI 10.1007/s10750-008-9501-2

FISH HABITAT MAPPING

Results of a short study of interactions of cetaceans and longline fisheries in Atlantic waters: environmental correlates of catches and depredation events

Gema Hernandez-Milian · Sabine Goetz · Catuxa Varela-Dopico · José Rodriguez-Gutierrez · Jorge Romón-Olea · José R. Fuertes-Gamundi · Edelmiro Ulloa-Alonso · Nick J. C. Tregenza · Andy Smerdon · Monserrat G. Otero · Vicente Tato · Jianjun Wang · M. Begoña Santos · Alfredo López · Rebeca Lago · Julio M. Portela · Graham J. Pierce

Abstract In the Atlantic, economic losses have been reported from shark, swordfish and tuna longline fisheries due to depredation by cetaceans. We examined interactions of odontocete cetaceans with commercial longliners operating in waters off Brazil and the Azores archipelago during 2006–2007, analysing relationships between catches, depredation on hooked fish, cetacean sightings, acoustic records of cetacean presence and environmental variables. Data were provided by skippers of six vessels and by on-board observers for two vessels. The percentage of longline sets depredated by cetaceans was low (ranging from 1% to 9% of total sets per ship) but the proportion of fish damaged was high (up to 100%) when depredation occurred. Catches were related to the phase of the moon, cloud cover, sea surface temperature and water depth whereas cetacean sightings were primarily related to catches. In particular there was a positive association between *Delphinus delphis* sightings and catches of swordfish, and between *Stenella frontalis* sightings and mako catches. Acoustic detection was low when depredation by false killer whales occurred although high

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Essential Fish Habitat Mapping in the Mediterranean

G. Hernandez-Milian (✉) · J. Wang · G. J. Pierce
University of Aberdeen, Tillidrone Avenue, Aberdeen AB24 2TZ, UK
e-mail: g.hernandez-m@abdn.ac.uk

S. Goetz · M. B. Santos · J. M. Portela · G. J. Pierce
Instituto Español de Oceanografía, Centro Oceanográfico de Vigo, Cabo Estai, Canido, 36200 Vigo, Spain

C. Varela-Dopico
Estación de Biología Mariña da Graña, University of Santiago de Compostela, Casa do Hórreo e Casa da Estrela, Rúa da Ribeira 1-4, A Graña, 15590 Ferrol, Spain

C. Varela-Dopico · J. Rodriguez-Gutierrez · J. Romón-Olea · J. R. Fuertes-Gamundi · E. Ulloa-Alonso
Cooperativa de Armadores de Pesca del Puerto de Vigo, Sociedad Coop. Ltda., Puerto Pesquero, Edif. Cooperativa de Armadores, Apdo. 1078, 36202 Vigo, Spain

N. J. C. Tregenza
Chelonia Limited, Beach Cottage, 5 Beach Terrace, Long Rock, Cornwall TR20 8JE, UK

A. Smerdon
Aquatec Group Ltd., High Street, Hartley Wintney, Hampshire RG27 8NY, UK

M. G. Otero · V. Tato
MG Otero Consultores SL, Porto Pesqueiro, Nvo Tinglado Xeral Empaque Of. 8, PO Box 1132, 36202 Vigo, Spain

A. López · R. Lago
CEMMA, Apdo. 15, 36380 Gondomar, Pontevedra, Spain

rates of clicks were detected when delphinids were sighted and false killer whales were by-caught. This may indicate that false killer whales are not echolocating when feeding on fish hooked on a longline.

Keywords Cetaceans · False killer whale · Longline fishery · Depredation · Hydrophones · Behaviour · Habitat modelling

Introduction

Pelagic longline fisheries in the Atlantic usually operate in offshore waters, mainly targeting tuna, swordfish, billfishes (Istiophoridae) and sharks (Brothers et al., 1999a). In contrast to the Pacific, catches of these species have not increased over the last decade (ICCAT, 2007). The most important Atlantic fishing grounds for longliners are located in the South Central tropical area and NW-W Azores waters (Lewison et al., 2004). The Spanish tuna and swordfish longline fishery is one of the most important in the Atlantic (ICCAT, 2007), a significant source of income for the Spanish fishing sector (Garza Gil et al., 2003). The lines used are approximately 50 miles long and typically carry 1200–1250 hooks.

Toothed whales (Odontoceti) are attracted to longlines because they provide an easily accessible source of food and the fish caught on them are often large. Cetaceans cause significant economic losses due to damage and removal of bait and hooked fish in a range of longline fisheries around the world (Northridge, 1984; Dahlheim, 1988; Ashford et al., 1996; Capdeville, 1997; Dalla Rosa & Secchi, 2002, 2007; Donoghue et al., 2002; Gilman et al., 2006; Zollett & Read, 2006; Ramos-Cartelle & Mejuto, 2007). Odontocetes are believed to develop familiarity with the sounds produced by longliners (such as the sound of the engine, the gear haulers and the electric equipment) and are frequently observed to follow vessels for days in order to take advantage of the catches (Gilman et al., 2006; Ramos-Cartelle & Mejuto 2007). Depredation rates tend to be higher for longer soak times (Gilman et al., 2007a, b).

In tropical and subtropical Atlantic waters, the killer whale (*Orcinus orca*, Linnaeus 1758) and the false killer whale (*Pseudorca crassidens*, Owen 1846) are known to interact with the pelagic longline fishery for tuna and swordfish (Dalla Rosa & Secchi, 2002, 2007; Dalla Rosa et al., 2006; Ramos-Cartelle & Mejuto, 2007). Killer whales and false killer whales are distributed in all oceans, the former best known from cooler waters and the latter preferring tropical, subtropical and warm temperate waters. Killer whales are found from the surf zone to 800 km from the coast, with large concentrations over the continental shelf, whereas false killer whales inhabit deep offshore waters. Both species mainly feed on fish, cephalopods and other marine mammals (Jefferson et al., 1993; Stacey et al., 1994; Carwadine, 1995). Environmental and oceanographic features, such as water temperature, bathymetry, oceanic fronts, lunar cycle, and spatio-temporal factors are believed to play an important role in the distribution of the cetaceans and their prey (e.g. Damalas et al., 2007; Romo et al., 2007; De Stephanis et al., 2008).

Marine mammal presence in offshore waters is usually determined by means of sightings recorded from vessels. However, use of passive acoustic methods, e.g. deployment of T-PODs (www.chelonia.com), can increase the detection rate, especially when visibility is low or the animals spend little time on the surface, and the range of detection may be wider than if only visual observation is used (Carstensen et al. 2006; Leeney & Tregenza 2006; Philpott et al., 2007).

The present short study aimed to describe the interactions of cetaceans, in particular killer and false killer whales, with longline fisheries for swordfish and tuna in two regions of the Atlantic (Brazil and Azores), determining the relationships between catches, cetacean presence, the incidence of depredation and environmental variables. Specifically: (1) Are the fish caught in particular places and is the size of catch related to environmental conditions? (2) Is cetacean presence and/or the occurrence of depredation related to particular environmental conditions? (3) Is depredation associated with the presence of particular cetaceans species and is it related to the amount of fish caught? Finally, since turtle by-catches were frequent we also investigated possible relationships between turtle by-catch, fish catch and environmental conditions.

Materials and methods

Sampling effort and study area

Data were gathered from eight Spanish commercial pelagic surface longline vessels, operating in Atlantic waters (1) off Brazil and extending into mid-Atlantic waters and (2) to the west of the Azores archipelago, between June 2006 and June 2007 (Fig. 1, Table 1). The two vessels with observers were fishing off Brazil (V7) and west of the Azores (V8), respectively.

The oceanography of the study area off Brazil is dominated by the South Equatorial Current, which has an offshoot along Brazil's North Coast (the North Brazil Current) and to the South (the Brazil Current). Offshore, in the waters of the Brazil Current, important fishery resources include *Thunnus albacares* in the southern region and *T. alalunga* in the northern region (Zavala-Camin & Antero da Silva, 1991), which are caught around seamounts and banks. The Brazil Current is a weak western boundary current carrying warm subtropical water with a temperature range of 18–28°C, which runs south along the coast of Brazil from about 9° S to about 38° S and is generally confined to the upper 600 m of the water column (Memery et al., 2000; Zavilov et al., 1999).

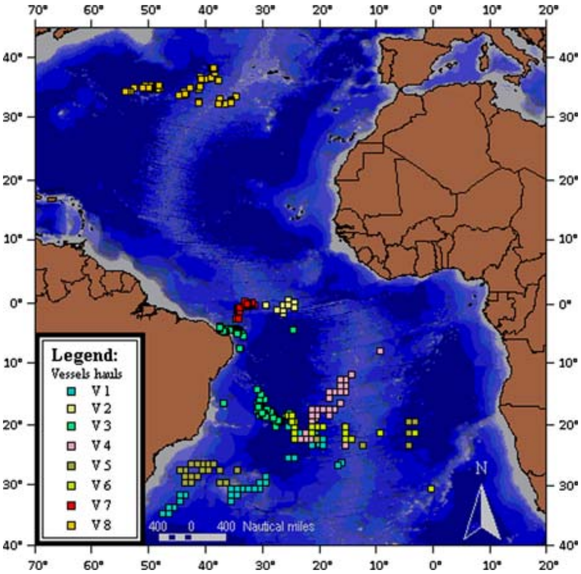

Fig. 1 Fishing areas of vessels V1–V8 in the Atlantic Ocean. Squares indicate where fishing operations took place

The second study area is to the west of the Azores archipelago, a group of nine volcanic islands situated on the Mid-Atlantic ridge, in an area dominated oceanographically by the Gulf Stream. The richness of fishing resources in the Azores originates from the complex relations between intermediate depth hydrothermal fields and seamount ecosystems. Tuna and swordfish are the most important target groups in the vicinity of the islands, although sharks—mainly blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*)—can outnumber swordfish 10:1 in longline catches (Morato et al., 2001).

Sampling methods

Skippers of six vessels (V1–V6) recorded data on catches of fish, cetacean sightings and depredation on catches. In addition, two vessels (V7 operating off North East Brazil between January and March 2007 and V8 operating South West of the Azores between April and June 2007) each carried a scientific observer on board, who registered data on fishing activity, cetacean sightings, acoustic detection of cetaceans, depredation on catches, and environmental data (Table 1).

Data on fishing activity included the time and location of each set, the number of hooks on the line, total catch (number and biomass of fish, by species) and any by-catch of marine mammals or sea turtles. The fish caught were identified as follows: swordfish (*Xiphias gladius*), shortfin mako (*Isurus oxyrinchus*), blue shark (*Prionace glauca*), tuna (*Thunnus* spp., mainly *T. alalunga*, *T. albacore*, and *T. Obesus*), marlin (Istiophoridae), dolphinfish (*Coryphaena hippurus*), barracuda (*Sphyraena* spp.) or garfish (Belonidae).

The number and species of fishes damaged by predators was logged and, based on the nature of the damage, the depredation was identified as due to cetaceans, sharks or other species, such as sea turtles. Fish damaged by cetaceans can be distinguished from shark-damaged fish since sharks typically bite the fish in half leaving clean borders or multiple smaller bites, whereas cetaceans such as killer whales and false killer whales tear the body of the fish, leaving bites with ragged borders and often just the head or the lips and upper jaw of the fish on the hook (Secchi & Vaske, 1998; Donoghue et al., 2002; Gilman et al., 2006; Varela-Dopico, pers. obs.). Fishermen report

Table 1 Fishing effort and depredation rates of eight Spanish commercial longline vessels operating in Atlantic waters (June 2006–July 2007): Vessel number (V1–V8), total no. of monitored sets per vessel, total no. of hooks deployed per vessel during monitored trips, average no. of hooks per set, average amount of catch per set (kg), percentage and number of sets with cetacean depredation, Spearman correlation coefficients (*r*) and associated probability (*P*) for the relationship between average weight of catches/set and total catch lost per vessel due to cetacean depredation (V1–V6: Both fish damaged and bait/fish removed from the hooks were considered; V7–V8: Only damaged fish was considered), and percentage and number of sets with sea turtle/marine mammal by-catch

Vessel	Sets	Hooks	Hooks/set	Average catch/set	Sets with cetacean depredation		Correlation between catch and depredation		% of Catch lost	Sets with by-catch		
										Sea turtles		Marine mammals
					%	No.	*r*	*P*		%	No.	No.
V1	76	102,600	1,350	1198.9	5.3	4	−0.07	0.547	1.6	10.5	8	0
V2	45	43,200	960	1574.7	8.9	4	−0.47	0.001	8.6	4.4	2	0
V3	126	163,800	1,300	886.1	5.6	7	−0.24	0.022	3.7	0	0	0
V4	137	185,358	1,353	1177.7	4.4	6	0.08	0.482	3.0	5.1	7	0
V5	94	116,100	1,235	1268.4	1.1	1	−0.01	0.934	0.2	10.6	10	0
V6	71	98,500	1,387	1715.6	4.3	3	−0.22	0.071	0.6	12.7	9	0
V7	30	37,673	1,256	2064.0	3.3	1	0.22	0.238	0.6	33.3	10	0
V8	56	62,198	1,111	1335.8	3.6	2	0.09	0.518	0.9	12.5	7	1
Total	635	809,429	1,275			28					53	1

Table 2 Number and percentage of sets monitored using different numbers of hydrophones (T-PODs), for vessels V7 (Brazil) and V8 (Azores)

Vessel	3 T-PODs		2 T-PODs		1 T-POD		No T-PODs		Total sets
	Sets	%	Sets	%	Sets	%	Sets	%	
V7	8	26.7	16	53.3	3	10.0	3	10.0	30
V8	55	98.2	0	0	0	0	1	1.8	56
Total	63		16		3		4		86

that cetaceans may occasionally also remove the fish entirely from the lines. Sea turtles leave several small bites on the fish, mainly eating the commercial parts (Varela-Dopico, pers. obs.).

Environmental data recorded on board by observers comprised sea state on the Douglas scale (Sea), cloud cover on a scale from 0 to 8 (Cd), moon phase (M1: new moon, M2: waxing moon, M3: full moon, M4: waning moon), sea surface temperature (SST) and water depth (Depth). In addition, bathymetry and coast line data for all trips were obtained from the GEBCO Atlas 2003, and a map was generated using ESRI Arc/View 3.3 (Fig. 1).

Sightings of cetaceans were recorded throughout fishing operations by the two observers, whereas sightings on the remaining six vessels were opportunistic. Geographic position, number of animals and species were recorded when they were sighted. The following categories were used: sperm whale (*Physeter macrocephalus*), killer whale (*Orcinus orca*), false killer whale (*Pseudorca crassidens*), common dolphin (*Delphinus delphis*), Atlantic spotted dolphin (*Stenella frontalis*), unidentified Odontoceti and Mysticeti.

Between one and three T-PODs (Table 2) were deployed along the line during most sets by vessels V7 and V8, in approximately 5 m water depth, one at each end and one in the middle. In order to prevent possible losses, they were attached to a buoy. The T-PODs used (version 5, www.chelonia.co.uk) detect clicks and click trains of specific cetacean species. They consist of a hydrophone, an analogue processor, a system to log echolocation clicks, and software that is able to filter cetacean clicks within a specific bandwidth. The T-PODs were programmed to detect false killer whales using parameters values calculated

Table 3 Number of clicks detected by the hydrophones for vessels V7 (Brazil) and V8 (Azores)

Vessel	CetHi		CetLo		Doubtful		Very doubtful		Positives		Negatives		Total
	Clicks	%	Clicks	%	Clicks	%	Clicks	%	Clicks	%	Clicks	%	
V7	17,186	21.3	21,253	27.0	21,782	27.0	20,400	25.3	68,268	84.7	12,352	15.3	80,621
V8	50,439	11.9	71,193	16.8	188,374	44.5	113,358	26.8	121,370	28.7	301,994	71.3	423,364
Total	67,625		92,446		210,156		133,758		189,638		314,346		503,985

CetHi, clicks with high probability of coming from a cetacean; CetLo, clicks with lower probability of coming from a cetacean; Doubtful, clicks which are often from cetaceans, but are sometimes unreliable; Very doubtful, click sequences which are more likely to arise from other sources; Positives, sum of CetHi + CetLo; Negatives, sum of doubtful and very doubtful; Total, Total number of clicks detected by the T-PODs regardless of source

for free-ranging false killer whales by Madsen et al., (2004) (filter A = 41 kHz, filter B = 16 kHz, bandwidth = 4–6, sensitivity = various, minimum click duration = 40 µs). They registered the number of clicks and classified the clicks according to the probability of coming from a false killer whale as high, low, doubtful or very doubtful (Table 3). *P. crassidens* produces echolocation sounds of 30–70 kHz (Madsen et al., 2004). However, this overlaps with the frequency range for other delphinid species, e.g. *Delphinus delphis* echolocation pulse frequency is between 20 and 100 kHz (Wood & Evans, 1980) and *Stenella* spp. emit clicks between 30 and 85 kHz (Lammers et al., 2003) or show bimodal click spectra with peaks at 40–60 kHz and 120–140 kHz (Schotten et al., 2003). Therefore the degree of species-specificity of the detections depends on the species present in the study area and in the present case was low due to the presence of both *Delphinus* and *Stenella*.

Data from the T-PODs were downloaded and stored on a laptop after hauling each line. Due to technical problems not all T-PODs worked all the time during the survey in Brazilian waters. In the Azores, T-PODs were used during all but one set. For each T-POD and each set, we extracted the number of clicks that were considered likely to come from delphinids ("positives", the sum of "CetHi" and "CetLo" categories, also known as "CetAll", see www.chelonia.co.uk) and the number of other clicks ("negatives"). Two additional indicators of cetacean activity were calculated (after Tougaard et al., 2004; Skov et al., 2002; Leeney & Tregenza, 2006): average click rate (the number of positive clicks divided by the total recording time) and click intensity (the mean number of positive clicks during minutes with clicks). Both indicators were calculated by T-POD and set.

Data analysis

Variables used for data analysis comprised descriptors of catch composition, occurrence and amount of depredation on catches, cetacean sightings, acoustic detections of cetaceans, and environmental data (see Table 4). Possible relationships between variables were initially explored using Spearman rank correlations, treating data from each set as a sample and analysing data from each vessel separately.

To provide a more detailed insight into relationships between response and explanatory variables, redundancy analysis (RDA) and generalised additive models were used with data from vessels 7 and 8 (recorded by observers). Data for Brazil and the Azores were analysed separately. For both surveys, (a) catches (numbers) of swordfish, tuna, shortfin mako and blue shark and (b) acoustic data on cetacean presence (click rate and click intensity) could be used as response variables for the RDA. For the Azores survey, there was sufficient data to also treat (c) cetacean sightings (numbers seen for *Delphinus delphis*, *Stenella frontalis*, *Orcinus orca*, *Pseudorca crassidens*, *Physeter macrocephalus*, Mysticetes and unidentified Odontocetes) and (d) incidence of depredation (numbers of damaged fish for swordfish, shortfin mako and escolar) as response variables. Thus, six RDA analyses were carried out in total (Table 5). In each case, all remaining variables were treated as explanatory variables. When using acoustic or depredation variables as response variables, cetacean sightings were converted to presence–absence data for use as explanatory variables, since we

Table 4 List of variables

Variables		Abbreviation	Descriptor
Fishery data	Catches of:		No. of fish caught or biomass of fish caught (kg)
	Swordfish (*X. gladius*)	XGL	
	Shortfin mako (*I. oxyrinchus*)	IOX	
	Blue shark (*P. glauca*)	PGL	
	Tuna (*Thunnus* spp.)	THU	
	Marlin (Istiophoridae)	IST	
	Dolphinfish (*C. hippurus*)	CHI	
	Barracuda (*Sphyraena* spp.)	SPH	
	Sharks (sum of all shark species)	Shark	
	Dimension of longline	Hook	No. of hooks
	Turtle by-catch	Turt	No. of animals by-caught
Acoustic data	Likely false killer whale clicks	Pos	No. of clicks
	Unlikely false killer whale clicks	Neg	
	Average click rate	Rate	No. of clicks/recording time
	Intensity of clicks	Ints	No. of clicks/minutes with clicks
Cetacean sightings	Sperm whale (*P. macrocephalus*)	PMA	No. of animals seen or presence of animals
	Killer whale (*O. orca*)	OOR	
	False killer whale (*P. crassidens*)	PCR	
	Common dolphin (*D. delphis*)	DDE	
	Atlantic spotted dolphin (*S. frontalis*)	SFR	
	Unidentified Odontoceti	ODO	
	Mysticeti	MIS	
Depredation	Swordfish (*X. gladius*)	XGLd	No. of fish damaged or presence of damage
	Shortfin mako (*I. oxyrinchus*)	IOXd	
	Escolar (*L. flavobrunneum*)	LFLd	
	Depredation (sum of all species)	dprd	
Environmental data	Sea state	Sea	Douglas scale: from 0 to 9
	Cloud cover	Cd	Scale: from 0 to 8
	Moon phase	M	M1: New moon
			M2: Waxing moon
			M3: Full moon
			M4: Waning moon
	Sea surface temperature	SST	in °C
	Water depth	Depth	in m

considered the visually confirmed presence or absence of cetaceans to be more important than the precise number present. RDA output indicates the proportion of variation in the response variables explained by the explanatory variables. The statistical significance of the effects of explanatory variables was obtained using a Monte Carlo permutation test with $n = 4{,}999$ permutations. The relationships between the response and explanatory variables were also displayed as point-vector biplots (see Zuur et al., 2007).

When RDA detected significant relationships between response and explanatory variables, these were further investigated using Generalised Additive Models (GAMs) and Generalised Linear Models (GLMs) for individual response variables within each of the four groups (catch, acoustic detections, sightings, and depredation), thereby allowing non-linearity in the relationships to be taken into account. Response variables could generally be assumed to follow binomial (presence–absence data) or Poisson

Table 5 Numerical output of the Redundancy analysis (RDA) for vessels V7 (Brazil) and V8 (Azores) indicating individual eigenvalues of the first and second axis (λ_1, λ_2), sum of all canonical eigenvalues (Sum), and results of *F* tests (*F* and associated probability, *P*) for the significance of effects of individual explanatory variables (only explanatory variables with significant effects are shown)

Vessel	Response variables	λ_1	λ_2	Sum	Explanatory variables	*F*	*P*
V7	Fish catches	17.91	12.21	0.46	Turt	2.92	0.010
					M4	2.40	0.032
	Acoustic data	33.62	0.68	0.34	M2	4.94	0.027
V8	Fish catches	24.59	13.69	0.47	M3	5.99	0.000
					Depth	3.14	0.017
					SST	3.00	0.019
					M4	0.04	0.037
	Acoustic data	46.68	0.54	0.47	DDE	8.27	0.004
					SFR	5.37	0.016
	Sightings	14.38	8.44	0.40	XGL	2.94	0.012
					M3	2.08	0.032
					Rate	2.10	0.034
					dprd	4.45	0.039
					IOX	2.70	0.045
	Depredation	30.42	6.95	0.44	PCR	21.72	0.001

When one set of variables (see Table 4) was used as response variables, all variables from the other four sets were potentially available as "explanatory" variables

(count data) distributions, with an addition parameter for dispersion included in the model if overdispersion was detected, and using appropriate link functions. The exceptions were click intensity, which was log-transformed to achieve an approximately Gaussian distribution, and average click rate, which had an approximately Gaussian distribution. For the Brazil data set both average click rate and click intensity were consistently low so the number of positive clicks was used as the response variable in GAMs. Cetacean sightings and depredation data were converted to presence–absence for use in GAMs and GLMs. Cloud cover (on a scale of 0–8) was treated as a continuous variable. For all continuous explanatory variables, degrees of freedom were constrained to be less than 5 to avoid overfitting.

The fitted GAMs had the general form:

$$y_i = \alpha + f_1(x_{i1}) + \ldots + f_m(x_{im}) + \beta_n x_{in} + \ldots + \beta_p x_{ip} + \varepsilon_i \quad \varepsilon_i \sim N(0, \sigma^2)$$

where y_i is the response variable, $f_j()$ are the smoothing functions, β_q are coefficients for parametric terms (e.g. dummy variables generated from categorical variables) and ε a random error parameter (Zuur et al., 2007). Models were fitted using a combination of forwards and backwards selection until all remaining terms were significant or none remained. Where none of the explanatory variables remaining was a continuous variable or could be treated as such, model fitting continued using generalised linear modelling (GLM). Plots of residuals were examined to confirm goodness of fit. RDA, GAMs and GLMs were performed using Brodgar 2.5.2 (www.brodgar.com). More information about these techniques can be found in Zuur et al. (2007).

Since turtle by-catch occurred quite frequently we also examined possible causal factors (environmental conditions and catch). Kruskal-Wallis tests were used to compare fish catches and environmental conditions during sets with and without turtle by-catch.

Results

Overall fishing effort, catches, by-catch and losses due to depredation

The fishing effort of the eight longline vessels monitored was located in the South Equatorial Current (V1–V7) and the Gulf Stream (V8) (Fig. 1). Between July 2006 and June 2007 the vessels performed 635 sets, deploying an average number of 1,275 hooks per set and catching a total of 1185.5 tons of marketable fish. Depredation by cetaceans occurred during between 1% and 9% of sets per vessel, with overall estimated losses (per vessel) between 0.2% and 8.6% of the total catch (V1–V6: Both fish damaged and bait/fish removed from the hooks were considered; V7–V8: Only damaged fish was considered) (Table 1).

By-catch of turtles was reported for all vessels, except for V3, occurring on an average in 11.2% of all sets. The number of turtles by-caught ranged between 1 and 5 animals per set. Leatherback turtle *Dermochelys coriacea* (39% of turtle individuals by-caught) and green turtle *Chelonia mydas* (31%) were the most frequently caught species, followed by loggerhead turtle *Caretta caretta* (19%) and Olive Ridley turtle *Lepidochelys olivacea* (11%). Most turtles were caught alive and released. Marine mammal by-catch was registered only once: during one set off the Azores, two false killer whales were caught on the longline (Table 1).

Catches and depredation on non-observer vessels

For the non-observer trips (V1–V6), skippers recorded that all catch damaged was due to cetacean depredation, based on the type of bite marks seen. The average percentage of sets depredated was low (4.6%) but when depredation occurred, between 2% and 100% of the catch was lost, with over 25% of the catch lost on two-thirds of these occasions. For two of the six vessels, the occurrence of depredation was significantly negatively correlated with catch (V2: $r = -0.47$, $P = 0.001$; V3: $r = -0.24$, $P = 0.022$) (Table 1), suggesting that depredation may significantly reduce catches.

Catches, by-catches and depredation on vessels with observers

The total catch of the two vessels with observers on board (V7 and V8) was 136.7 tonnes (3,645 individuals) of fish, of which 87% (by number) were marketable. The main species caught off Brazil (V7) by number were tuna (54.5%), swordfish (29.4%) and marlin (7.5%). Off the Azores (V8), the principal species caught by number were sharks (73.6%, blue sharks and shortfin mako sharks) and swordfish (24.6%). Depredation of catches occurred during 19 out of 86 sets: nine times off Brazil and ten times off the Azores. However, based on visual inspection of the damaged fish, this was attributed to cetaceans, presumed to be false killer whales, on only three occasions, once off Brazil (3.3% of sets) and twice off the Azores (3.6% of sets) (Table 1). This compares to twelve instances of depredation by sharks and four that were attributed to turtles. The overall proportion of catches (by number) damaged by cetaceans across all sets was only 0.2% and 0.9% of total catch, respectively. The fish damaged by cetaceans were swordfish (85.7% by number) and shortfin mako (14.3% by number).

RDA results indicated that catches of the principal target species off Brazil were significantly related to turtle by-catch and moon phase (waning moon) (Table 5, Fig. 2). GLM results indicated weakly significant relationships between swordfish catches and both cloud cover and the interaction between moon phase and cloud cover. In the case of tuna catches the only effect that was marginally significant

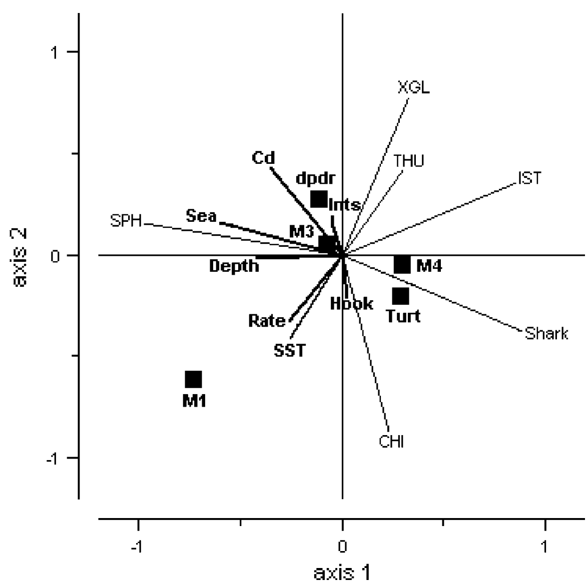

Fig. 2 RDA biplot for catch data from vessel V7 (Brazil). Response variables (represented by thin lines): Catches of swordfish (XGL), tuna (THU), barracuda (SPH), dolphinfish (CHI), marlin (IST), garfish (AGU) and sharks (Shark). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4 for abbreviations. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

Table 6 GAM and GLM results using data from vessel V7 (Brazil, $N = 30$ sets)

Response variables	Explanatory variables	Type	t	F	P	Sign	edf	%dev	AIC
XGL								29.2	211.6
	Moon	N			All >0.05				
	Cd	L	2.22		0.0364	+			
	Cd-M3	N	−2.08		0.0492	−			
THU								45.2	302.6
	Moon	N			All >0.05				
	Cd	N	1.71		>0.05				
	M2-Cd	N	−2.12		0.0448	−			
Pos								51.9	838.2
	M1	N	−2.93		0.0084	−			
	M2	N	2.45		0.0237	+			
	Depth	S		3.49	0.0263		3.64		

The response variables were catches (number) of swordfish and tuna per set, and the number of likely delphinid echolocation clicks. In all cases, a quasi-Poisson distribution was assumed for the response variable. Results displayed are as follows: explanatory variables (and interactions) included in the final model, whether they were included as smoothers (S), linear terms (L) or nominal variables (N), their significance (based on F or t tests, with P-value), the direction (sign) of the effect (+ or −) and degrees of freedom for smoothers. Also given are the overall percentage of deviance explained (%dev) and AIC value for the model. Full moon (M4) was used as the reference value when evaluating effect of moon phase (since there was only one record with new moon). Explanatory variables used: Table 4

was the interaction term, with both main effects (cloud cover, moon phase) non-significant (Table 6). The co-plot (Fig. 3) illustrates the interaction between the effects of cloud cover and moon phase

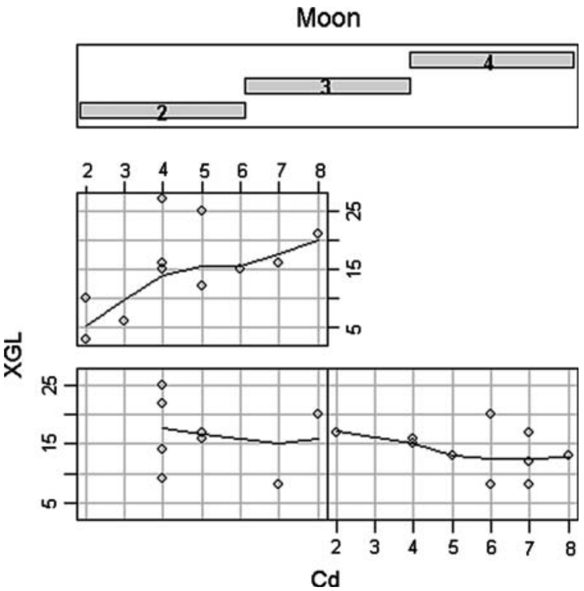

Fig. 3 Co-plot for swordfish catches by vessel V7 (Brazil), illustrating the interactions between effects of moon phase and cloud cover

in relation to swordfish catches. Due to the small sample size, further investigation of these relationships is not possible.

Off the Azores, RDA showed catches of the three main fish species were related to moon phase, water depth and SST (Table 5, Fig. 4). GAMs showed that swordfish catches were related to water depth, moon phase, cloud cover and sightings of *Stenella frontalis* (Table 7). Catches peaked at a cloud cover value of 2 (Fig. 5a), showed a minimum value at around 3,000 m depth (increasing in shallower and deeper waters) (Fig. 5b) and decreased in the presence of *Stenella*. Given that spotted dolphins are unlikely to remove large fish from the lines, the interpretation of the latter relationship is unclear.

Mako catches off the Azores showed significant relationships with moon phase, SST, click rate and sightings of *Delphinus delphis* and *Stenella frontalis* (Table 7). Catches were lower at higher temperatures and lower at the highest values for click rate (Fig. 5c). Catches were strongly negatively associated with presence of common dolphins and positively associated with presence of spotted dolphins. Finally blue shark catches were related to moon phase, with higher catches around full moon (Table 7).

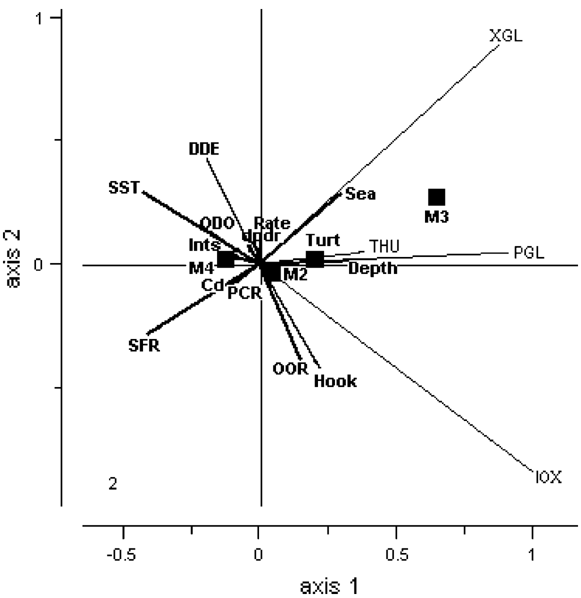

Fig. 4 RDA biplot for catch data from vessel V8 (Azores). Response variables (represented by thin lines): catches of swordfish (XGL) tuna (THU), shortfin mako (IOX) and blue shark (PGL). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

In the Brazil survey, turtle by-catch occurred during 10 out of 30 sets and was not related to depth, SST, moon phase, sea state or catches of tuna or swordfish. Turtle by-catch was associated with higher catches of sharks (Kruskal-Wallis test, $P = 0.002$) and “other species” ($P = 0.001$). In the Azores survey, turtle by-catch occurred during seven of 56 sets, and was weakly positively associated with shortfin mako catches ($P = 0.035$).

Acoustic data collected during observer trips

T-PODs were deployed on 96.5% of lines. It was not always possible to set three T-PODs in each line, but 92% of the lines had two or three T-PODs that registered acoustic data (Table 2). Data were obtained covering approximately 96% of the time that the T-PODs were in the water, the remaining 4% being lost due to technical problems.

Off Brazil, hydrophones registered a low number of click trains, of which 84.7% were classified as “positive”, i.e. likely to have been produced by delphinids. Off the Azores, the number of clicks registered was considerably higher but only 28.7% of clicks were “positive” (Table 3). During both surveys, when depredation by false killer whales occurred, click intensity was low (Fig. 6a, b). However, on one occasion five swordfish were removed and two false killer whales were by-caught during the same set (set 20) off the Azores, and click intensity registered by the T-POD closest to the by-caught animals was high.

Redundancy analysis for the acoustic data from Brazil showed that the number of likely delphinid clicks recorded was affected by moon phase (waxing moon) (Table 5, Fig. 7). GAM showed that the detection of likely delphinid clicks was highest over the deepest water and confirmed the effect of moon phase (Table 6; Fig. 5d). During this survey depredation by false killer whales was recorded for only one fish.

In the Azores survey, RDA analysis revealed that acoustic detections were related to sightings of small delphinids (*Delphinus delphis* and *Stenella frontalis*) (Table 5, Fig. 8). GLM results indicated that click intensity was weakly related to sightings of spotted dolphins and moon phase (waning moon) although unrelated to other environmental factors or to catches. Average click rate, however, was positively related to depth (Table 7).

Cetacean sightings recorded by observers

The number of cetacean sightings differed for the two study areas: off Brazil, only 12 false killer whales and one sperm whale were sighted. No further analysis of these data was carried out.

Off the Azores 613 individual cetaceans were sighted, of which 94% were Odontoceti species (*Stenella frontalis*, *Delphinus delphis*, *Pseudorca crassidens*, *Physeter macrocephalus* and *Orcinus orca* in descending order of occurrence). Peaks of clicks were detected by the T-PODs when sightings of dolphins, false killer whales and killer whales were reported. RDA analysis showed that cetacean sightings were related to catches of swordfish and shortfin mako, moon phase, click rate and occurrence of depredation (Table 5, Fig. 9).

Satisfactory models could be fitted only for the two most commonly sighted species (*Delphinus delphis* and *Stenella frontalis*). The presence of

Table 7 GAM and GLM results using data from vessel V8 (Azores)

Response variables	Explanatory variables	Type	*t* or *z*	*F* or χ^2	*P*	Sign	edf	%dev	AIC
XGL								55.9	305.5
	M2	N	−2.83		0.0068	−			
	SFR	N	−2.92		0.0054	−			
	Cd	S		3.52	0.0138		2.9		
	Depth	S		5.96	0.0006		2.6		
IOX								70.8	276.7
	M2	N	2.90		0.0058	+			
	M3	N	2.74		0.0089	+			
	M4	N	−2.12		0.0393	−			
	SST	S		13.78	0.0006		1		
	Rate	S		4.57	0.0036		4		
	DDE	N	−4.63		0.0016	−			
	SFR	N	3.88		0.0020	+			
PGL								16.4	443.9
	M3		2.54		0.0141	+			
Ints								22.8	83.3
	M4	N	−2.29		0.0263	−			
	SFR	N	2.12		0.0390	+			
Rate								24.1	391.0
	Depth	S		16.82	0.0001		1		
DDE								38.7	52.2
	XGL	L	2.56		0.0105	+			
	IOX	L	−2.24		0.0252	−			
	Ints	L	1.97		0.0486	+			
SFR								45.7	54.2
	M2	N	−2.53		0.0114	−			
	M3	N	−2.68		0.0073	−			
	XGL	L	−2.69		0.0072	−			
	IOX	L	2.28		0.0225	+			
	Rate	L	3.02		0.0025	+			
dpdr								25.9	46.8
	Rate	L	2.053		0.0400	+			
	DDE	N	−2.13		0.0332	−			
	SFR	N	−2.60		0.0094	−			

The response variables were catches (number) of swordfish, shortfin mako and blue shark per set, intensity of clicks, average click rate, sightings of *Delphinus delphis* and *Stenella frontalis* and depredation. In all cases, a quasi-Poisson distribution was assumed for the response variable. Results displayed are as follows: explanatory variables (and interactions) included in the final model, whether they were included as smoothers (S), linear terms (L) or nominal variables (N), their significance (based on F, χ^2, z or t tests, with P-value), the direction (sign) of the effect (+ or −) and degrees of freedom for smoothers. Also given are the overall percentage of deviance explained (%dev) and AIC value for the model. New moon (M1) was used as the reference value when evaluating effect of moon phase. Explanatory variables used: Table 4

D. delphis was related to higher catches of swordfish and lower catches of shortfin mako catches. The presence of *Stenella frontalis* was associated with higher mako catches and lower swordfish catches. Both species were more frequently sighted when detection of "positive" clicks was high. In addition,

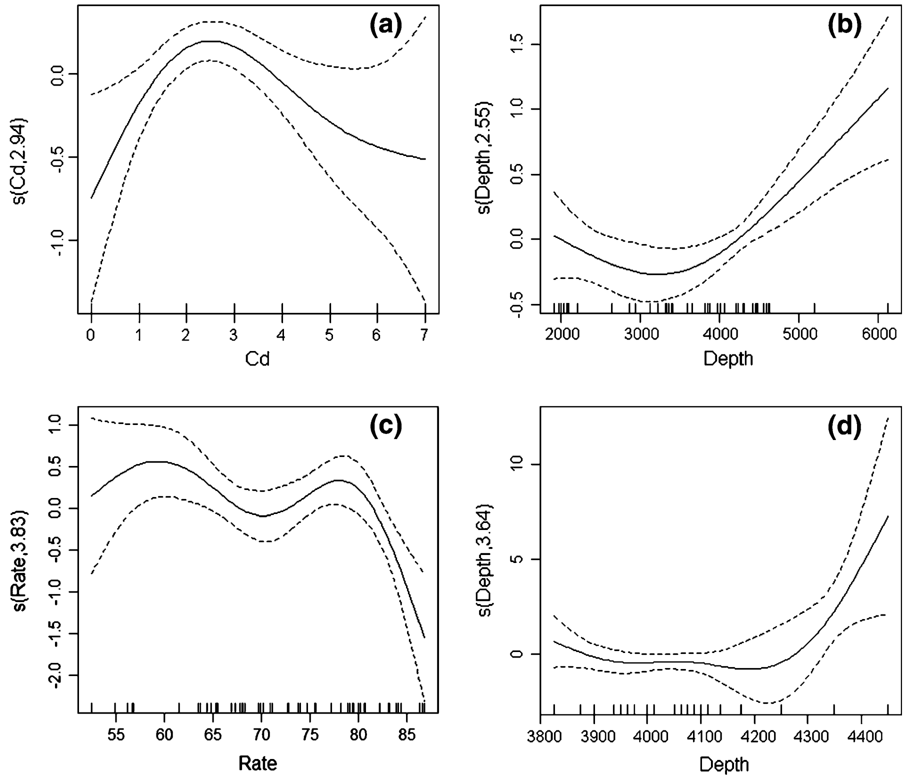

Fig. 5 GAM results: Azores (V8)—smoothing curves for partial effect of (**a**) cloud cover and (**b**) water depth on swordfish catches, and (**c**) click rate on mako catches. Brazil (V7)—smoothing curve for partial effect of (**d**) water depth on the number of likely delphinid clicks recorded. Dotted lines indicate 95% confidence bands

sightings of *Stenella frontalis* were lower during full and waxing moon (Table 7).

Depredation

Nine fish were depredated during the Brazil survey of which only one may have been depredated by false killer whales. Further statistical analysis was therefore not possible.

During the Azores survey, depredation affected three species (swordfish, shortfin mako and escolar), but false killer whales probably mainly removed swordfish. RDA suggested that depredation was related with sightings of false killer whales (Table 5, Fig. 10). The GLM, however, revealed that the occurrence of depredation increased when click rate was high and sightings of small delphinids (*D. delphis* and *S. frontalis*) were low (Table 7).

Discussion

Our results suggest that catches of the main target species of the fishing vessels observed were affected by environmental variables such as light conditions (cloud cover and moon phase), water temperature and water depth. Tuna, swordfish and sharks are all oceanic migratory species, which are mostly found in temperate surface waters where thermal fronts and upwelling processes occur (Collette & Nauen, 1983; Bigelow et al., 1999; Brill et al., 1999; Dagorn et al., 2000; De Stephanis et al., 2008). They show diel vertical movement patterns, feeding at the surface layer during the night (Nakamura, 1985; Bigelow et al., 1999; Domokos et al., 2007) and descending to deeper waters during the day. Therefore, longlines targeting these species are usually set in surface waters around sunset, soaking during the night, and hauled around sunrise.

Based on this small data set, moon phase appears to have an important effect on swordfish and shark catches. This was also found in other areas, e.g. the Pacific (Pallares & Garcia-Mamolar, 1985; Bigelow et al., 1999) and the Mediterranean (Damalas et al., 2007). Cloud cover also affects seabird by-catch on longlines. A higher intensity of moon and daylight (depending on moon phase and cloud cover) may improve the visibility of bait on the lines and

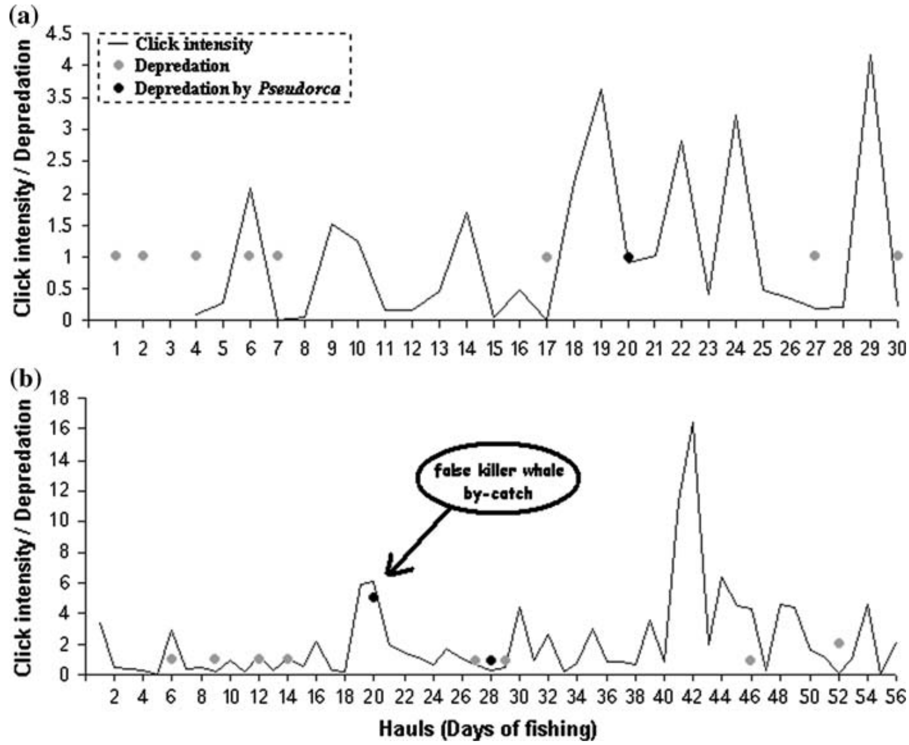

Fig. 6 Click intensity and occurrence of depredation for (**a**) vessel V7 (Brazil) and (**b**) vessel V8 (Azores), by set

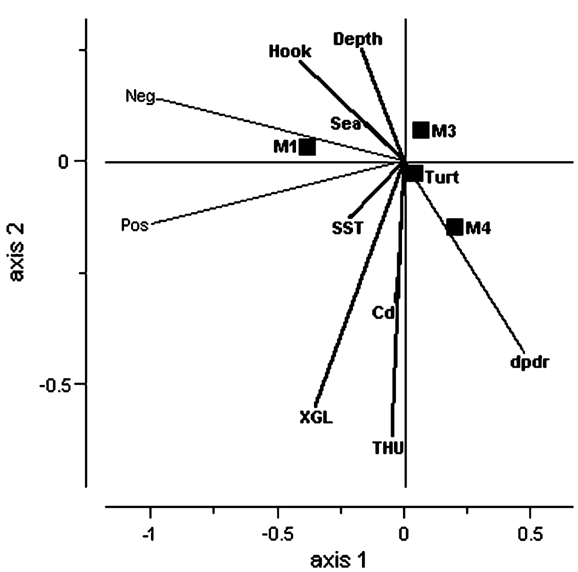

Fig. 7 RDA biplot for acoustic data from vessel V7 (Brazil). Response variables (represented by thin lines): likely delphinid clicks (Pos) and unlikely delphinid clicks (Neg). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

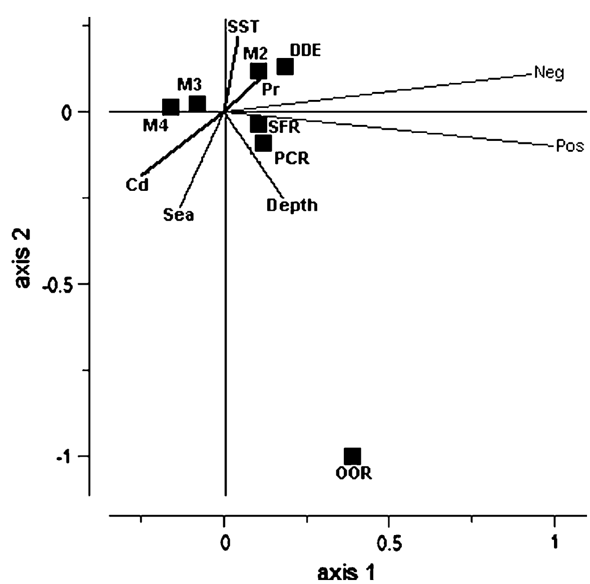

Fig. 8 RDA biplot for acoustic data from vessel V8 (Azores). Response variables (represented by thin lines): likely delphinid clicks (Pos) and unlikely delphinid clicks (Neg). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

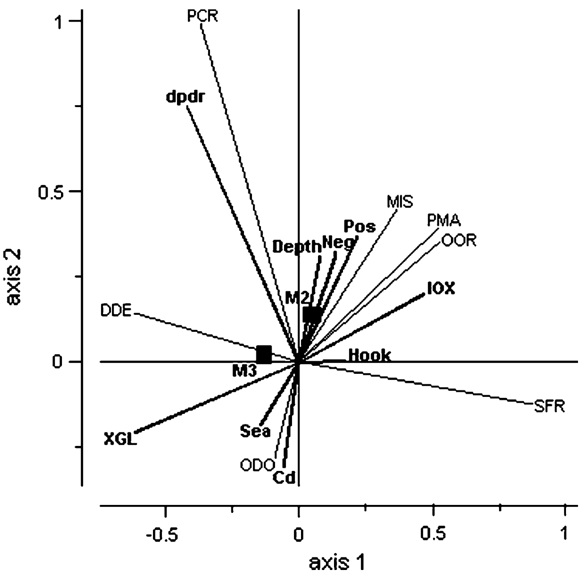

Fig. 9 RDA biplot for cetacean sightings data from vessel V8 (Azores). Response variables (represented by thin lines): Sightings of Mysticetes (MIS), *Delphinus delphis* (DDE), *Stenella frontalis* (SFR), *Pseudorca crassidens* (PCR) and *Orcinus orca* (OOR), *Physeter macrocephalus* (PMA) and not identified odontocetes (ODO). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

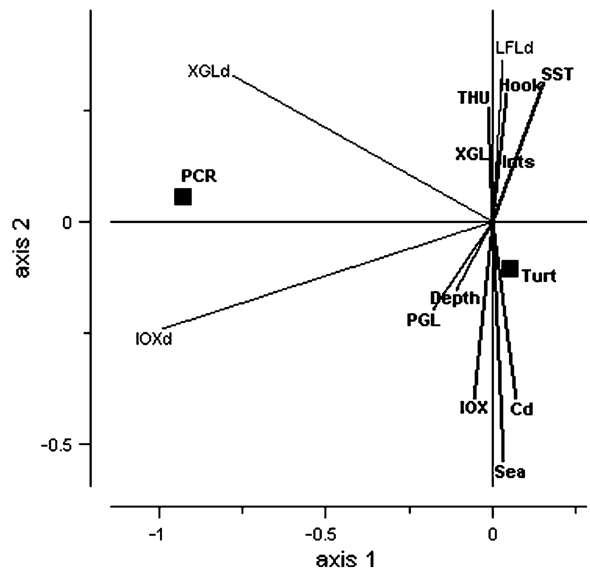

Fig. 10 RDA biplot for depredation data from vessel V8 (Azores). Response variables (represented by thin lines): Depredation on swordfish (XGLd), shortfin mako (IOXd) and Escolar (LFLd). Explanatory variables (represented by thick lines if continuous and by squares if nominal): see Table 4. The plot shown was based on re-running the RDA having removed the least important (non-significant) explanatory variables, to achieve greater visual clarity

therefore attract more fish (and sea birds) to the fishing gear (Cherel et al., 1996; Brothers et al., 1999a, b).

Bigelow et al. (1999) found that swordfish CPUE in the northern Pacific Ocean was lowest over a range of 2,000–3,000 m bottom depth, and then increased in deeper water. Our results suggest that a similar relationship applies in Atlantic waters.

The by-catch rate of cetaceans during our study was very low and similar to rates reported by Dalla Rosa & Secchi (2002). Two false killer whales were by-caught during one set off the Azores. This is consistent with the observation by Perrin et al. (1994) that, although cetacean by-catch is a major issue in fishing gear such as gillnets and trawls, with longlines it occurs only occasionally.

The frequency of false killer whale sightings was very low, perhaps because they were primarily feeding underwater on fishes hooked on the line (between 15 and 100 m water depth) and were therefore not visible for observers. Other delphinids, however, were frequently sighted. *Delphinus delphis* sightings off the Azores were more frequent when catches of swordfish were high and mako catches were low, while for sightings of *Stenella frontalis* it was the other way around. This might indicate that both delphinid species share the same habitat, but feed on different prey. However, other studies suggest that the trophic ecology of *Delphinus delphis* and *Stenella frontalis* is quite similar (Aguiar dos Santos & Haimovici, 2001).

Although they are unlikely to prey directly on large swordfish and mako sharks, respectively, they may feed on the same fish and squid species that are taken by these species. The association between swordfish and dolphins may be similar to the strong tuna-dolphin (*D. delphis* and *Stenella* species) association found in other areas (e.g. Hall & Donovan, 2002; Reeves & Reijnders, 2002). This association was originally exploited by fishermen in the Eastern Tropical Pacific where yellowfin tuna swam underneath dolphins and were thus located.

T-PODs are useful to give insight into cetacean activity under water. However, analysis of acoustic data in relation to sightings data suggested that most of the recorded clicks came from small delphinids, which produce echolocation sounds in the same frequency range as those emitted by false killer whales. False killer whales, like other odontocete species, use biosonar to echolocate their prey. Fishes hooked on a surface longline are easy to prey on and the use of echolocation may not be necessary for feeding on them.

In our study, both observer and skipper data indicate that the frequency of depredation on pelagic longlines operating in Atlantic waters was low. Less than 1% of the overall catch per trip was lost during both trips when scientific observers were on board. However, if depredation occurred, the amount of catch lost per set reported by skippers exceeded 25% on most occasions and could reach up to 100%. Similar results were reported by Dalla Rosa & Secchi (2007), Kock et al. (2006), Poisson et al. (2007) and Ramos-Cartelle & Mejuto (2007). When depredation occurred, the economic loss could be as high as 40% of the value of the catches, including vessel operation costs and fishing time lost (ARVI, unpublished data). A possible reason for the low incidence of depredation is that skippers avoid fishing areas where cetacean presence is known to be high in order to reduce interactions (Dahlheim, 1988). However, fishermen think that these animals learn to follow the longline vessels (e.g. Poisson & Taquet, 2000; Donoghue et al., 2002). It should be noted that depredation rates may be underestimated because only damaged fish were counted when calculating depredation rates, while fish removed entirely from the hooks could not be quantified.

Our results suggest that false killer whale was the main marine mammal predator removing catch from the longlines, although few instances were recorded and depredation by sharks was four times as frequent as that attributed to marine mammals. Although the species most frequently sighted in our study were *D. delphis* and *S. frontalis*, dolphins were hardly ever observed when depredation occurred which indicates that they were most likely not feeding on the hooked fish. Therefore, the co-occurrence of depredation and cetacean clicks may have been coincidental. For two of the non-observer vessels, the amount of fish caught was significantly lower when depredation by false killer whales occurred. In addition, RDA suggested a relationship between the occurrence of depredation and sightings of *Pseudorca* for the observer vessels and the only by-catch of false killer whales coincided with the removal of five swordfish from the line during one set. Dalla Rosa & Secchi (2007) reported that depredation on longline fisheries targeting swordfish in Brazilian waters was primarily caused by killer whales, but occasionally by other cetaceans such as false killer whales. However, their research was carried out closer to the coast where killer whales are more abundant (Jefferson et al., 1993).

False killer whales mainly feed on fish and cephalopods (Koen-Alonso & Pedraza, 1999; Hernandez-Garcia, 2002; Ramos-Cartelle & Mejuto, 2007). Previous studies (Secchi & Vaske, 1998; Gilman et al., 2006; Zollett & Read, 2006) demonstrated that fish hooked on longlines was becoming a new resource, changing the feeding customs of the cetaceans. According to Ramos-Cartelle & Mejuto (2007), the cetaceans learnt to use the bait and catches retained on the fishing gear as an ‘easy’ prey to capture and thereby reduce the energy costs of feeding. They seem to be selective when taking fish from the lines (Kock et al., 2006). In our study, the main fish species consumed by cetaceans was swordfish. This was also found by Poisson & Taquet (2000) and Dalla Rosa & Secchi (2007). However, off Brazil tuna was the main fish captured and sharks were the main target species (followed by swordfish) off the Azores. Thus the consumption of swordfish might indicate a preference of the cetaceans for this species, as suggested by Dalla Rosa & Secchi (2007) and Poisson and Taquet (2000).

While observers reported depredation by sharks and other animals, skippers on the other six vessels reported depredation in general, with the assumption that false killer whales were responsible being based on sightings of this species alongside the boats. Donoghue et al., (2002) indicated that fish damaged by sharks may be inaccurately reported. Skippers may not distinguish between different types of bite marks.

Turtle by-catch was frequent, especially when a higher number of sharks were caught, and involved at least four different turtle species. Carranza et al. (2006) found that mako sharks preyed upon various species of sea turtles in the Equatorial Eastern Atlantic. This might also apply in our study area. Several instances of damage to hooked fish were attributed to turtles. Although in this study most turtles were apparently released alive, turtle by-catch remains a major issue in longline fisheries, one which can possibly be reduced by use of alternative hook designs and bait or by fishing deeper (e.g. Gilman et al. 2007a, b).

Conclusions

In our study, catch rates were influenced by environmental parameters such as light conditions, SST and water depth, whereas cetacean presence was mainly related to the catch rates of particular fish species, possibly indicating trophic relationships between species. Acoustic recordings probably reflected the presence of delphinids in general rather than false killer whales in particular and it is possible that false killer whales preying on longlines do not need to use biosonar to locate their prey. The depredation rate and the overall amount of catch consumed during our survey were low, but when depredation occurred, the proportion of catch lost mostly exceeded 25%. Although the statistical analysis revealed some potentially interesting relationships between catches, cetacean presence, depredation and environmental variables, it is important to note that this was a small-scale study: we analysed data from 86 observed sets and more data are needed to further explore and quantify these relationships.

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